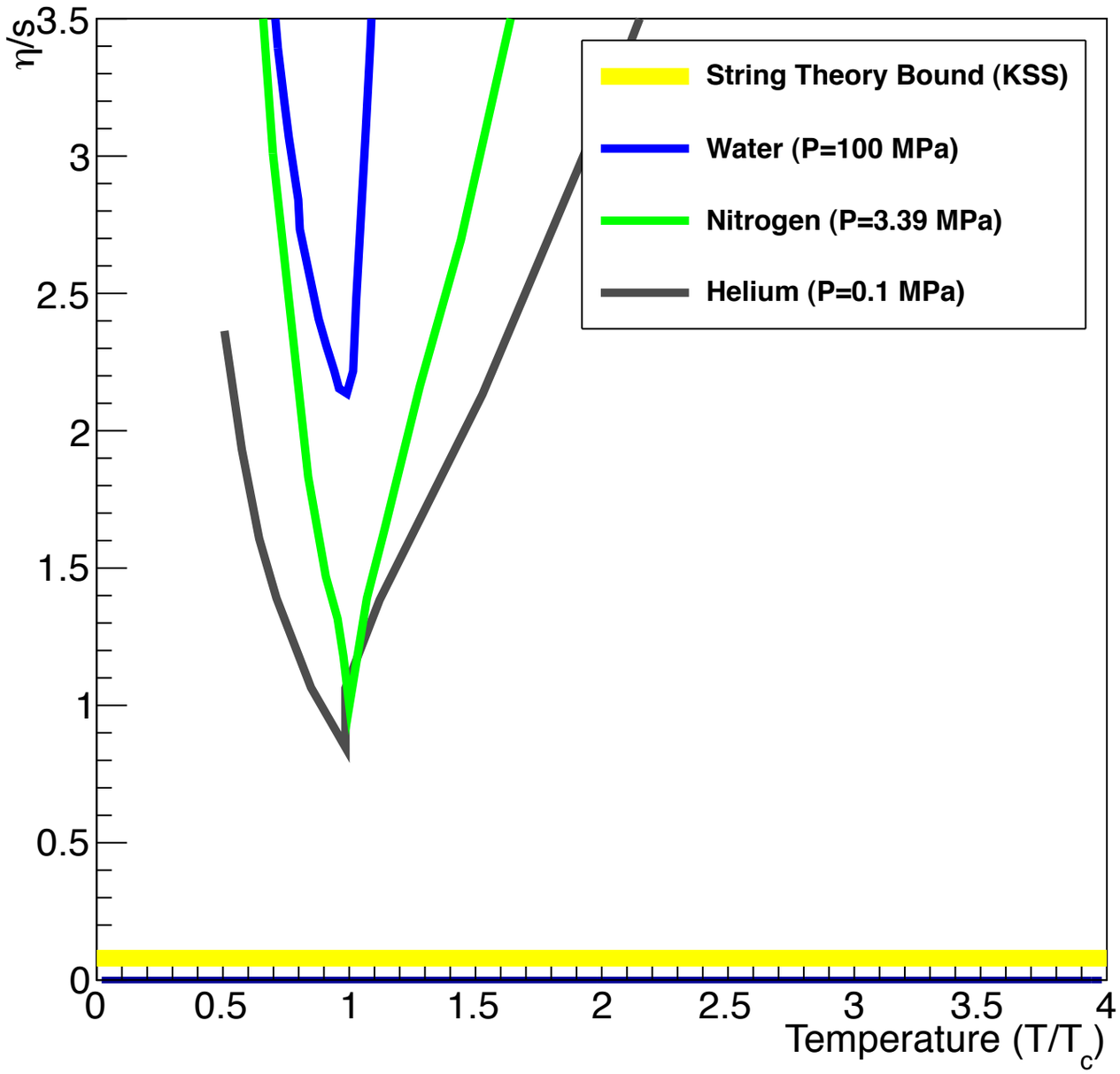
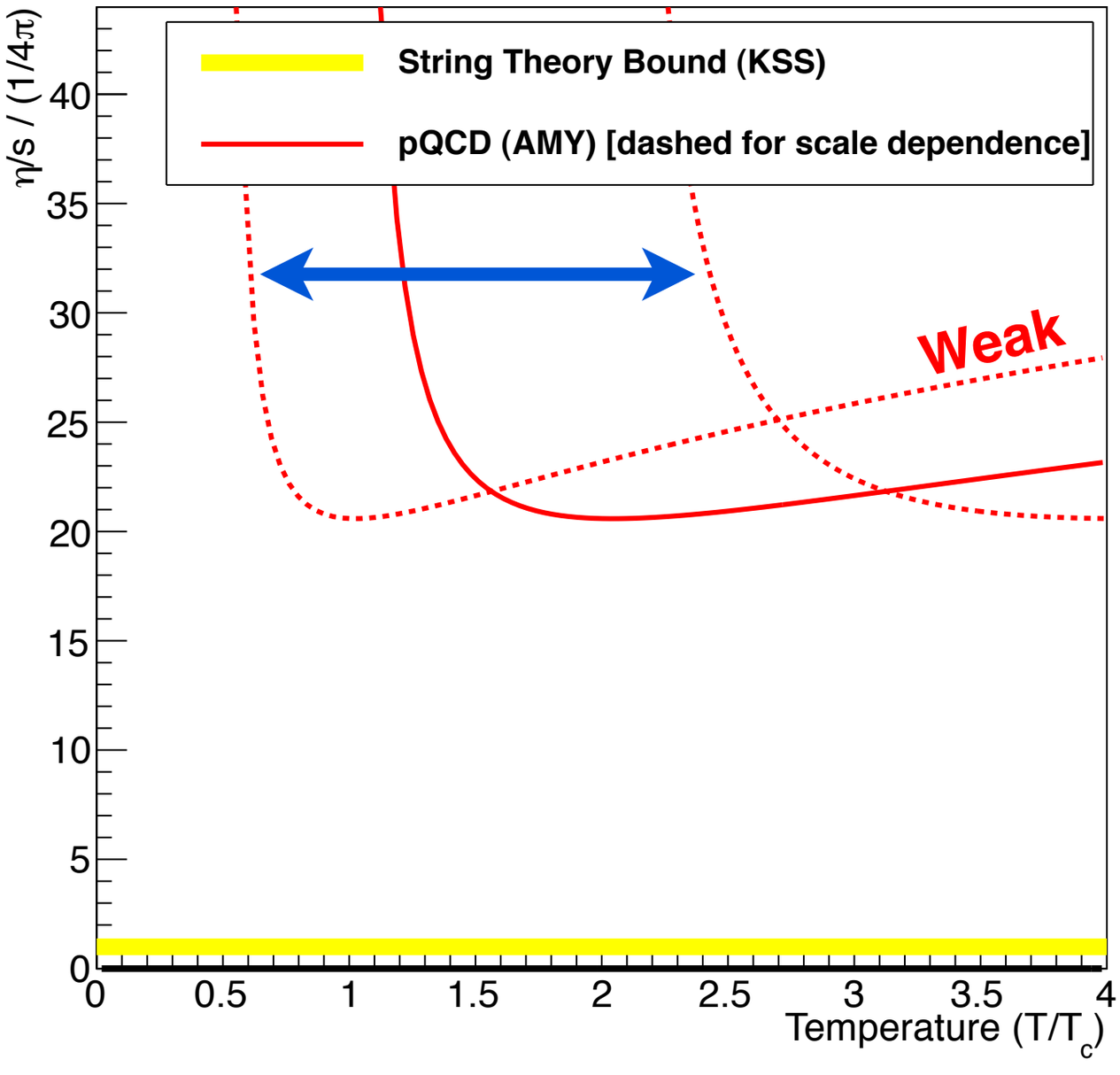
Jet Measurements in Heavy Ion Collisions with an Upgraded PHENIX Detector

Dave Morrison (BNL)
for the PHENIX Collaboration

An η/s compendium

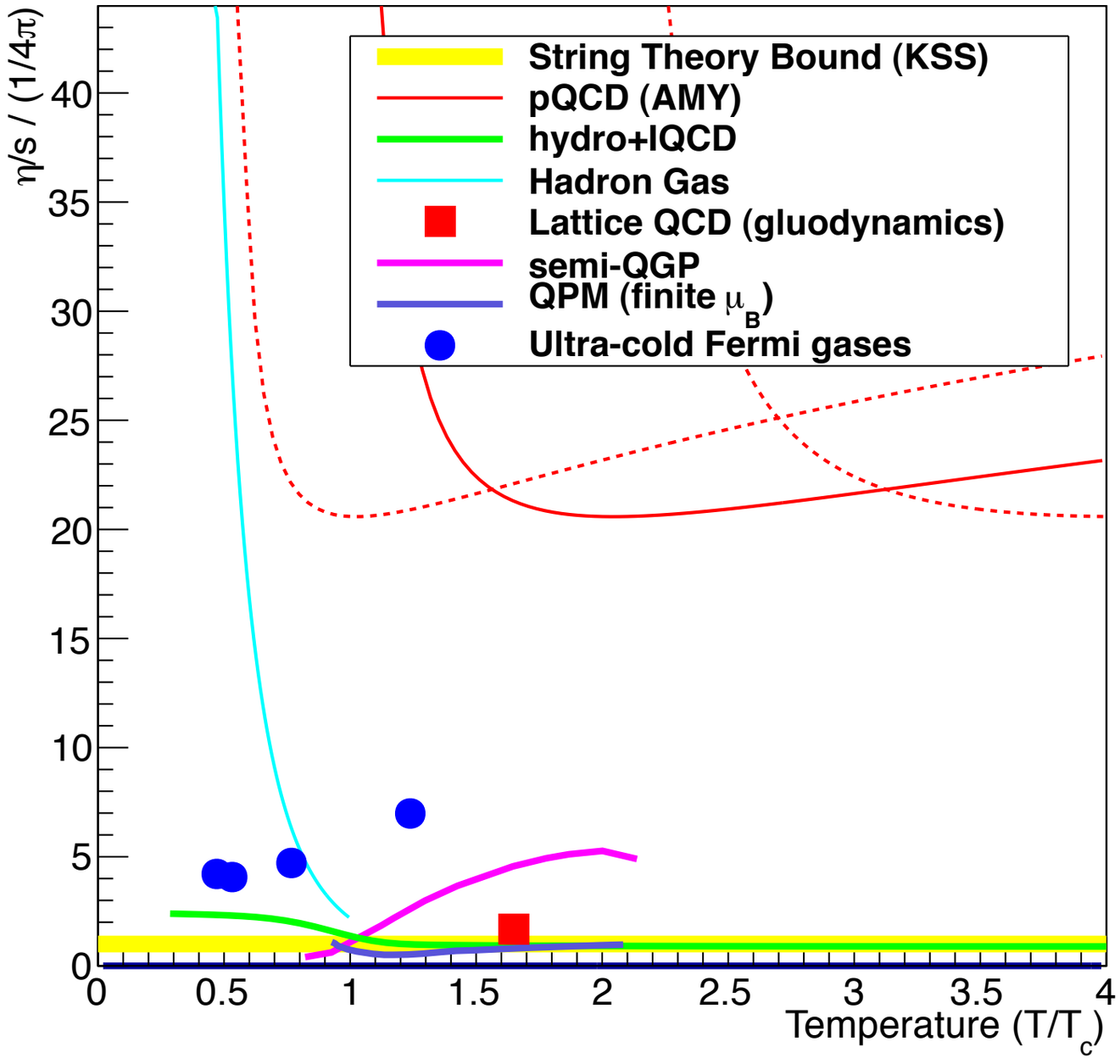


Strong coupling vs weak coupling



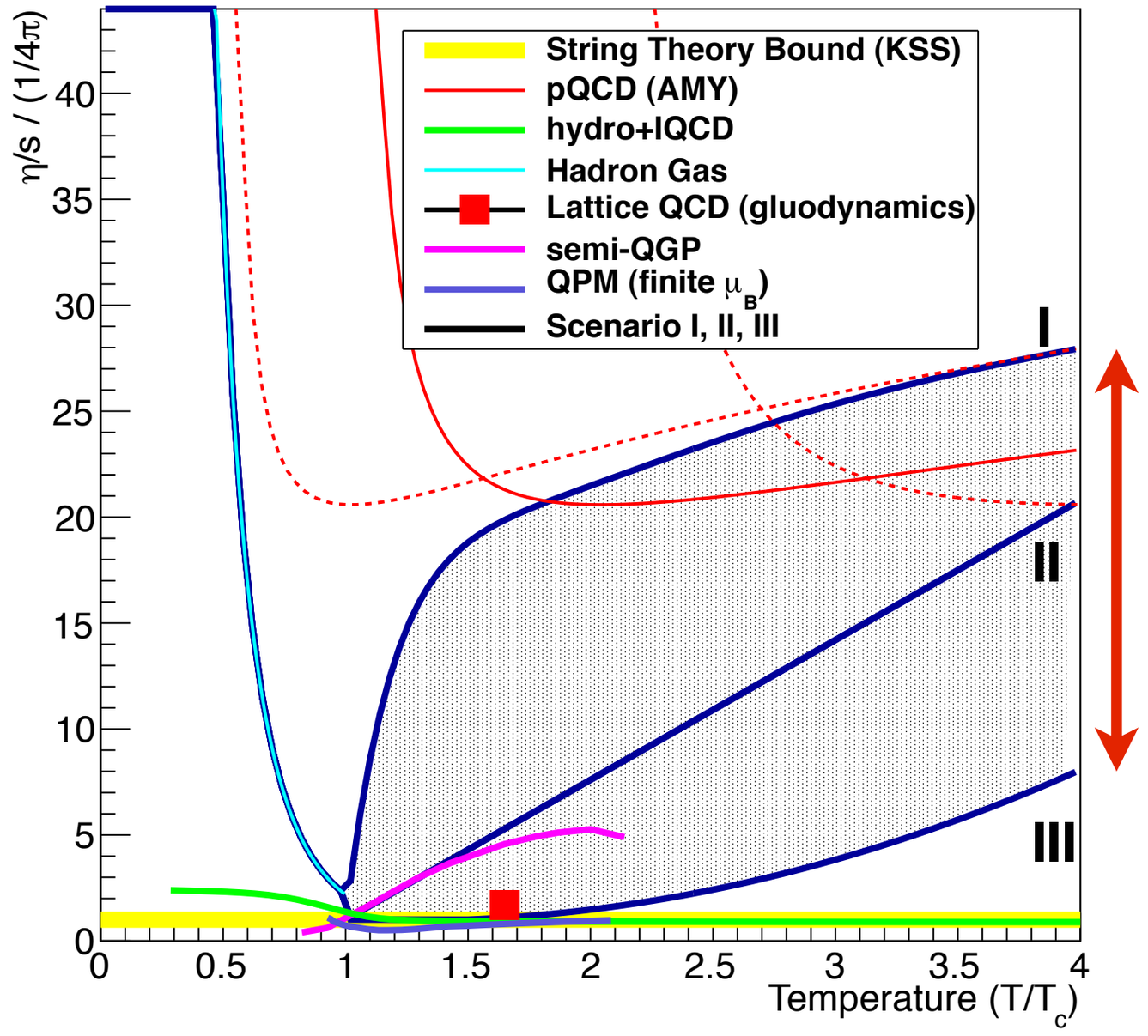
scale dependence

Strong coupling calculations (and a bit of data)



Hydro + IQCD calculation from Kovtun, Moore, and Romatschke
arXiv:1104.1586
Hadron gas calculation from Prakash (almost 20 years ago) $1/T^4$.
Phys. Rept. 227 (1993) 321-366
Lattice QCD result from Harvey Meyer (gluodynamics)
arXiv:0704.1801
QPM, finite μ_B calculation from Shrivistava and Singh
arXiv:1201.0445
Semi-QGP calculation from Rob Pisarski with $\kappa = 8$
arXiv:0912.0940
Ultra-cold Fermi gases from Adams, Carr, Schäfer, Steinberg, Thomas
arXiv:1205.5180v1

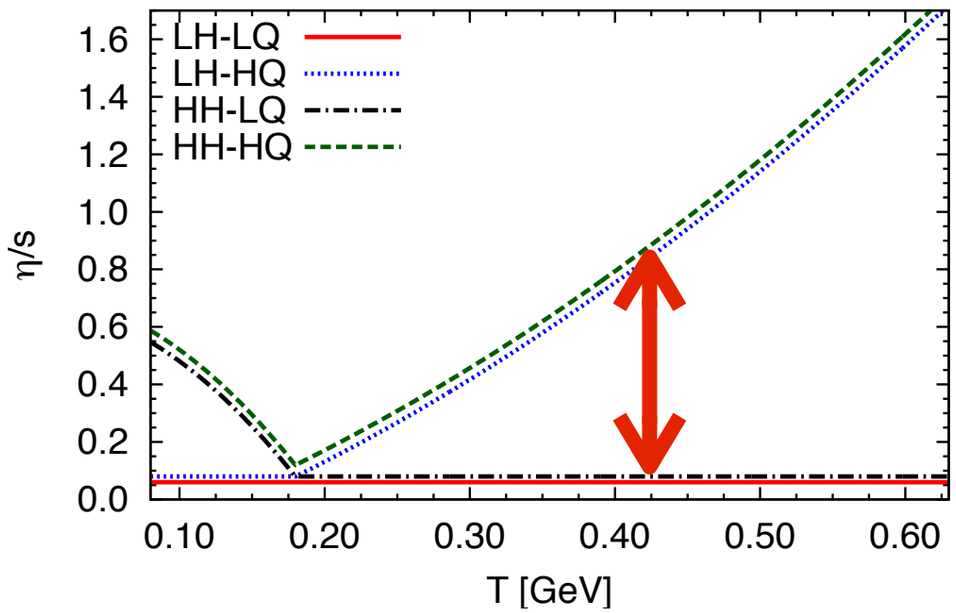
How does the QGP evolve from strong to weak?



variety of evolution scenarios

Is this transition associated with changes in quasi-particles, excitations, strong fields?

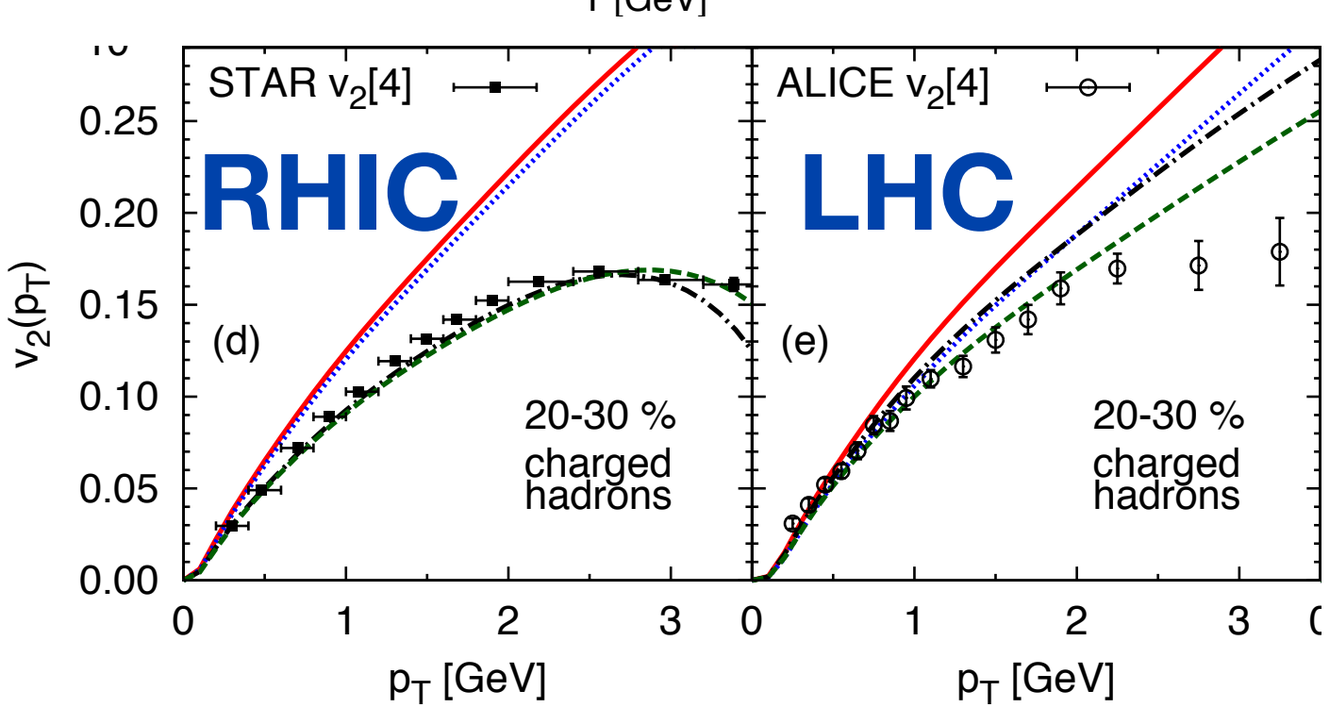
Complementarity of hydrodynamics and jets



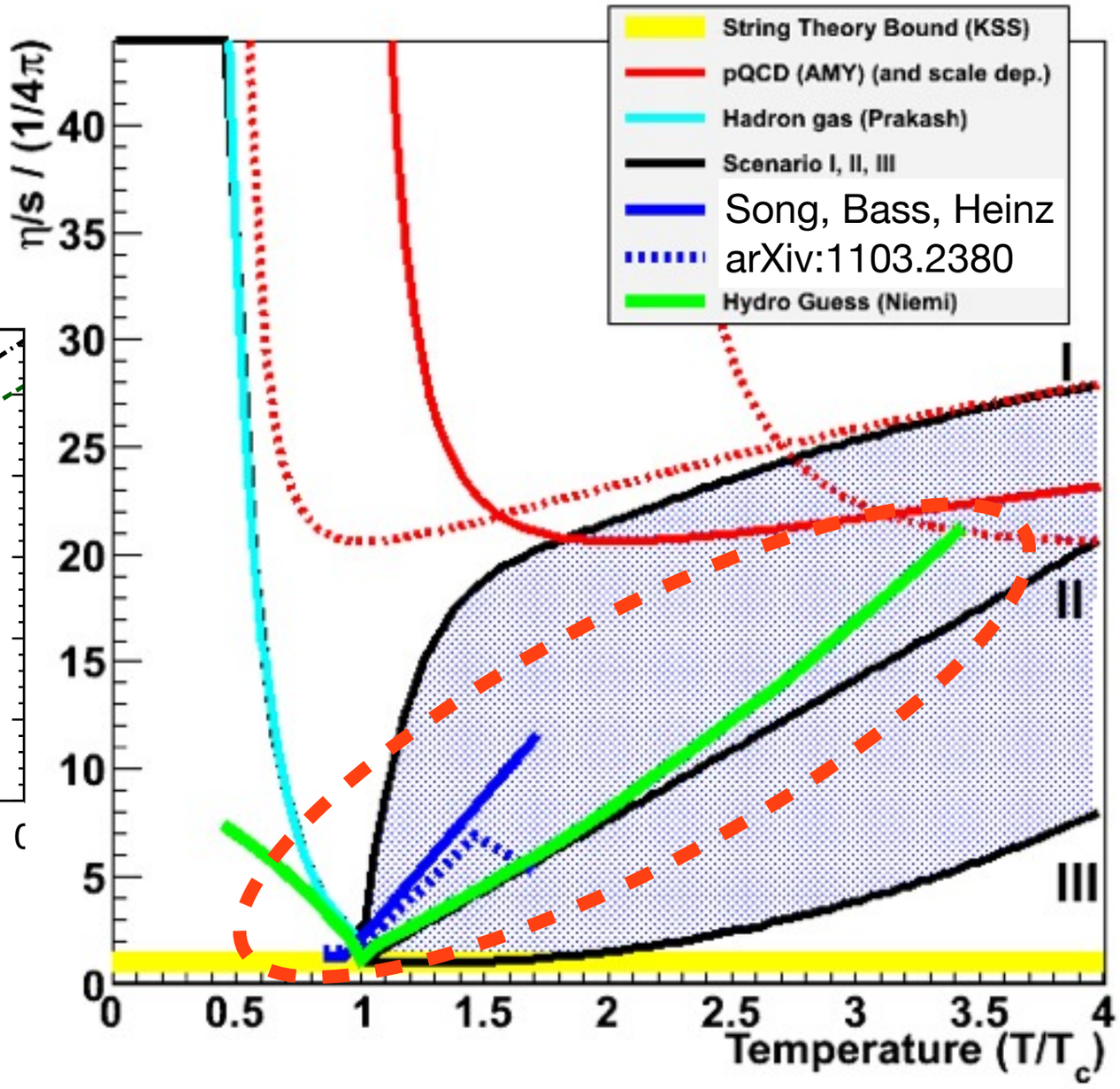
Recent study of η/s(T) arXiv:1101.2442

Niemi, Denicol, Huovinen, Molnár, Rischke

10x KSS bound increase in η/s by 2.5 T_c



Almost zero effect at RHIC and
<15% effect at LHC in flow pattern!

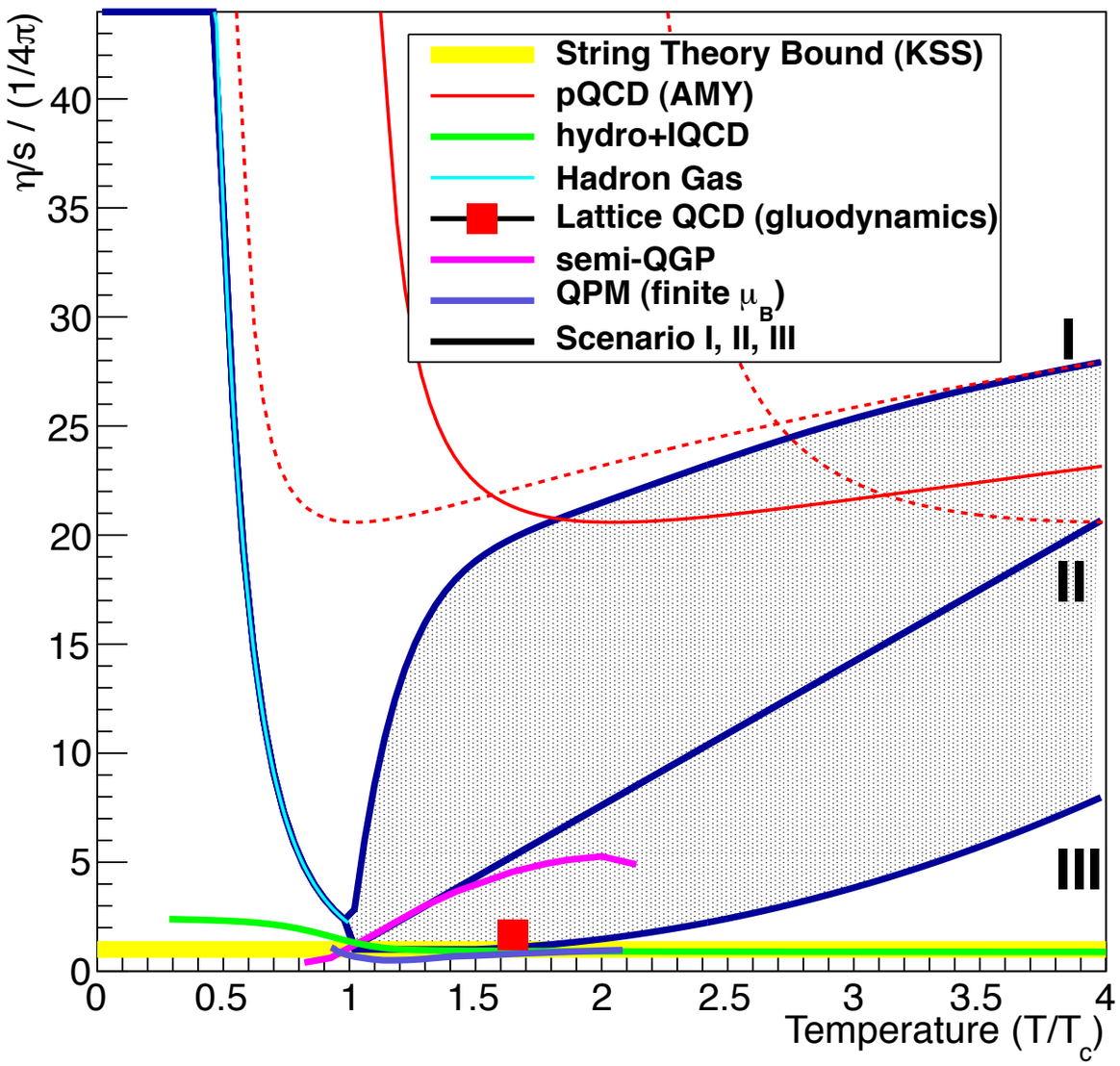


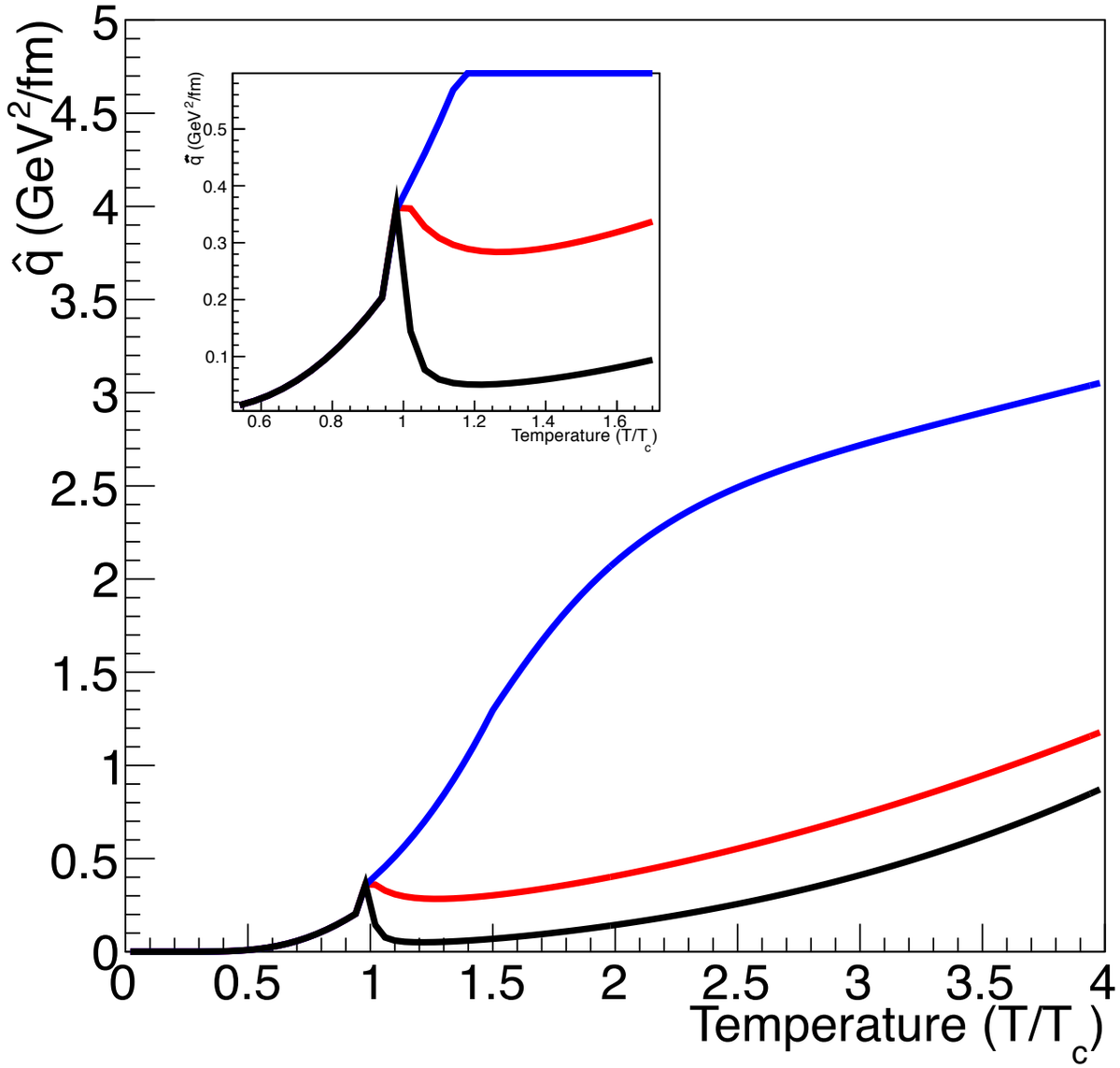
Relating viscosity/entropy to transport coefficient

"Small shear viscosity implies strong jet quenching"
A. Majumder, B. Muller, X.N. Wang, PRL (2007)

$$\hat{q} = \frac{1.25T^3}{\eta/s}$$

valid for weak coupling – measure both to explore transition from weak to strong coupling





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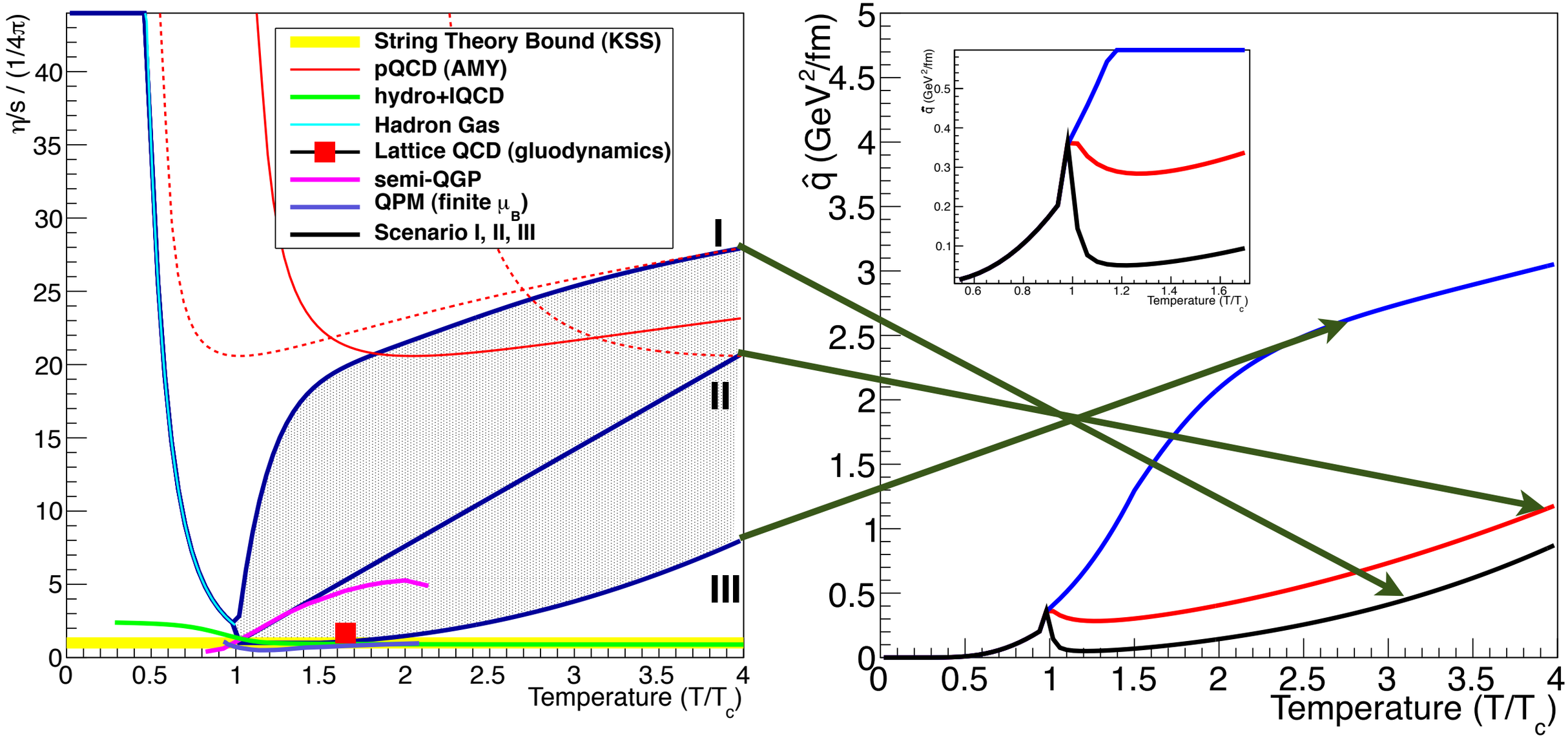
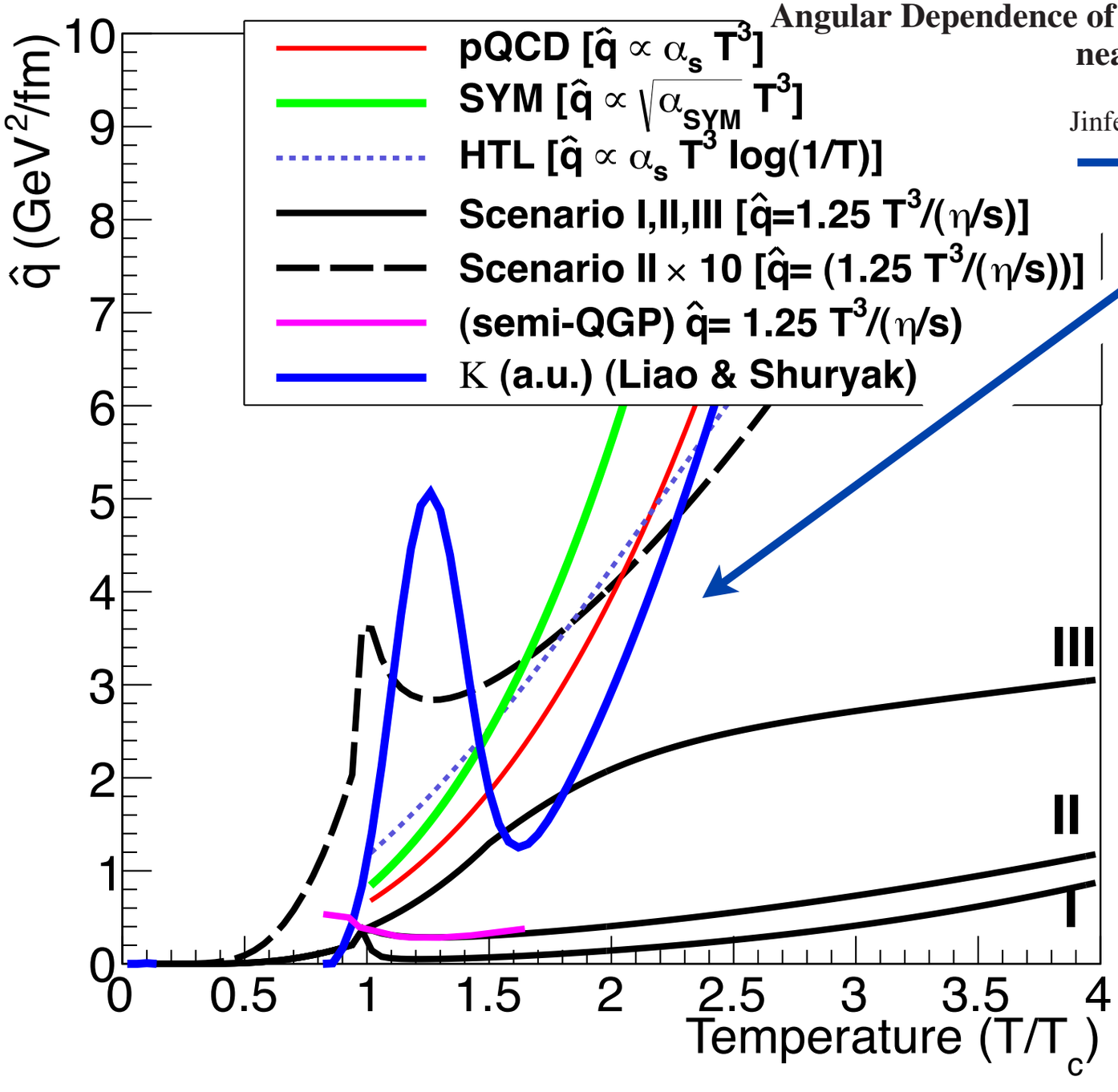


Many possibilities for $\hat{q}(T)$ near T_c

PRL **102,** 202302 (2009) PHYSICAL REVIEW LETTERS week ending 22 MAY 2009

Angular Dependence of Jet Quenching Indicates Its Strong Enhancement near the QCD Phase Transition

Jinfeng Liao[1,2,*] and Edward Shuryak[1,†]



"[We find] the jet quenching is a few times stronger near T_c relative to the QGP at $T > T_c$."

What *is* the nature of the strongly coupled QGP?

- How does the strongly coupled quark-gluon plasma emerge from an asymptotically free theory of quarks and gluons?

- How rapidly does the quark gluon-plasma transition from the most strongly coupled system near T_c to a weakly coupled system of partons?

- What are the dynamical and other underlying changes to the medium as one crosses this temperature expanse?

    - quasi-particles? excitations? other?

Theoretical guidance on observables/sensitivity

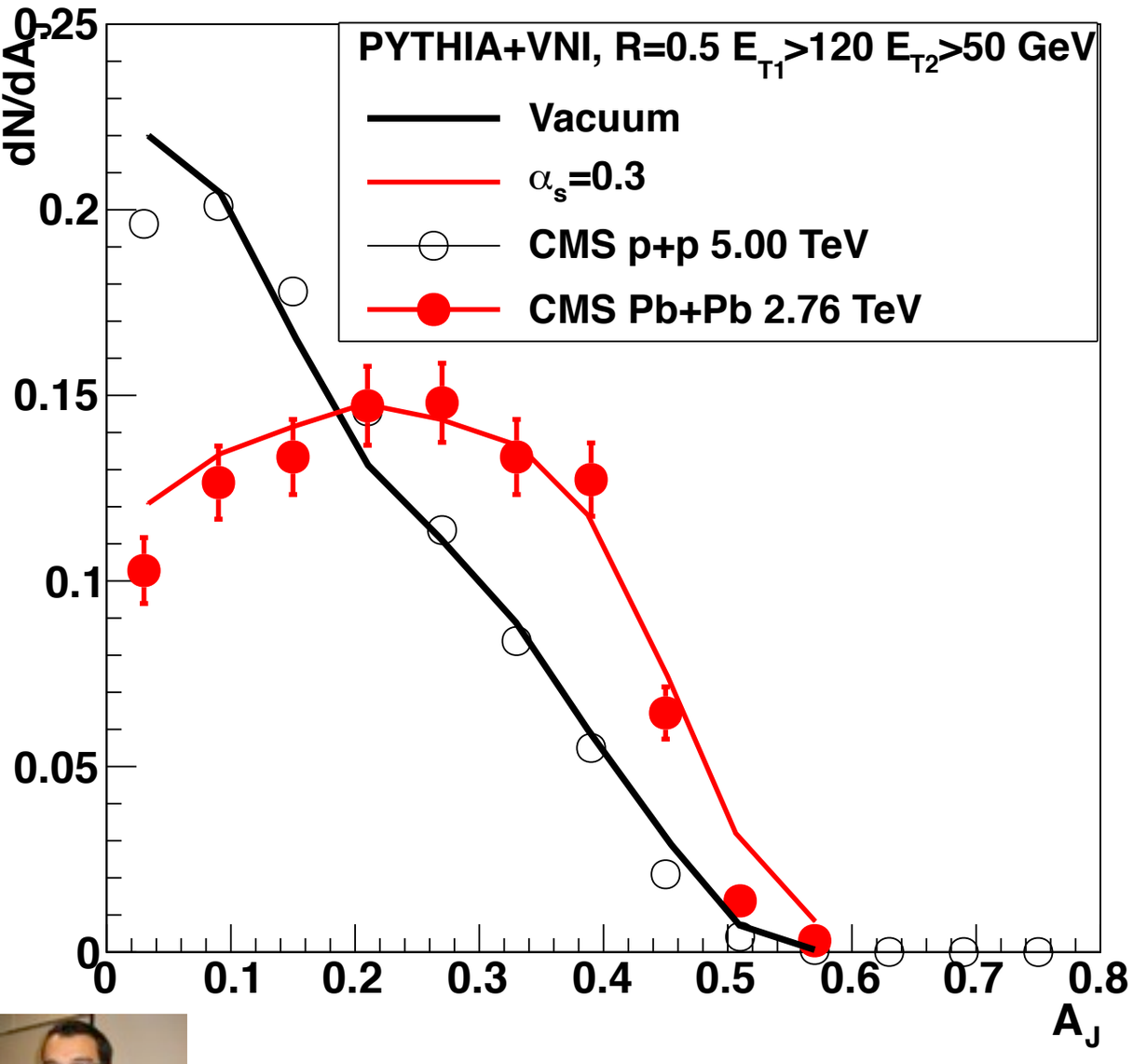
The theoretical bridgework needed to connect measurement to the interesting and unknown medium properties of deconfined color charges is under active construction by many theorists

Just one example: March 3-4, 2012 Jet Collaboration meeting at Duke University
Lots of interest from theory community

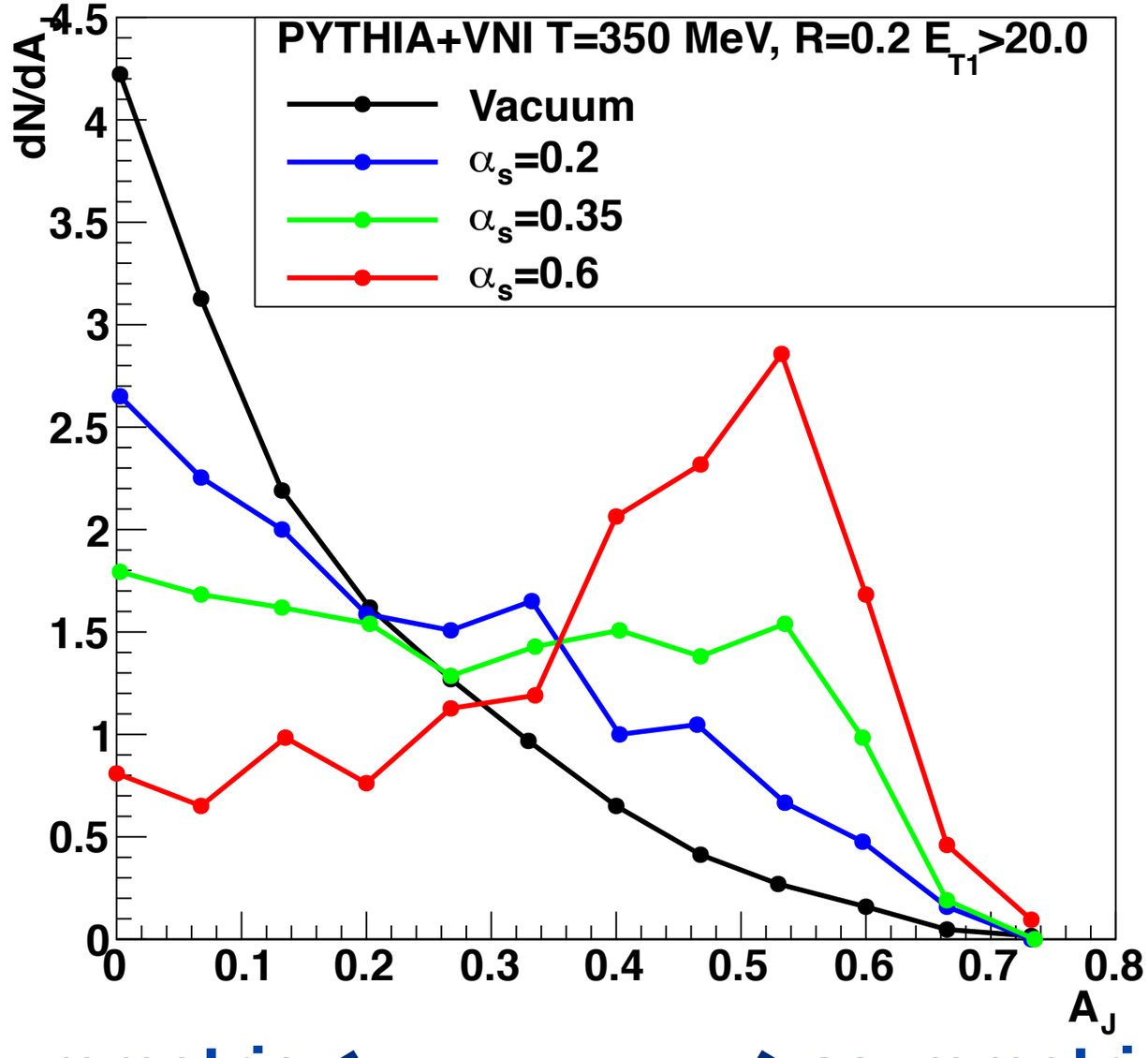
Follow up EVO meetings.

Sensitivity to coupling strength

Comparison to LHC data



Sensitivity to α_s at RHIC energies

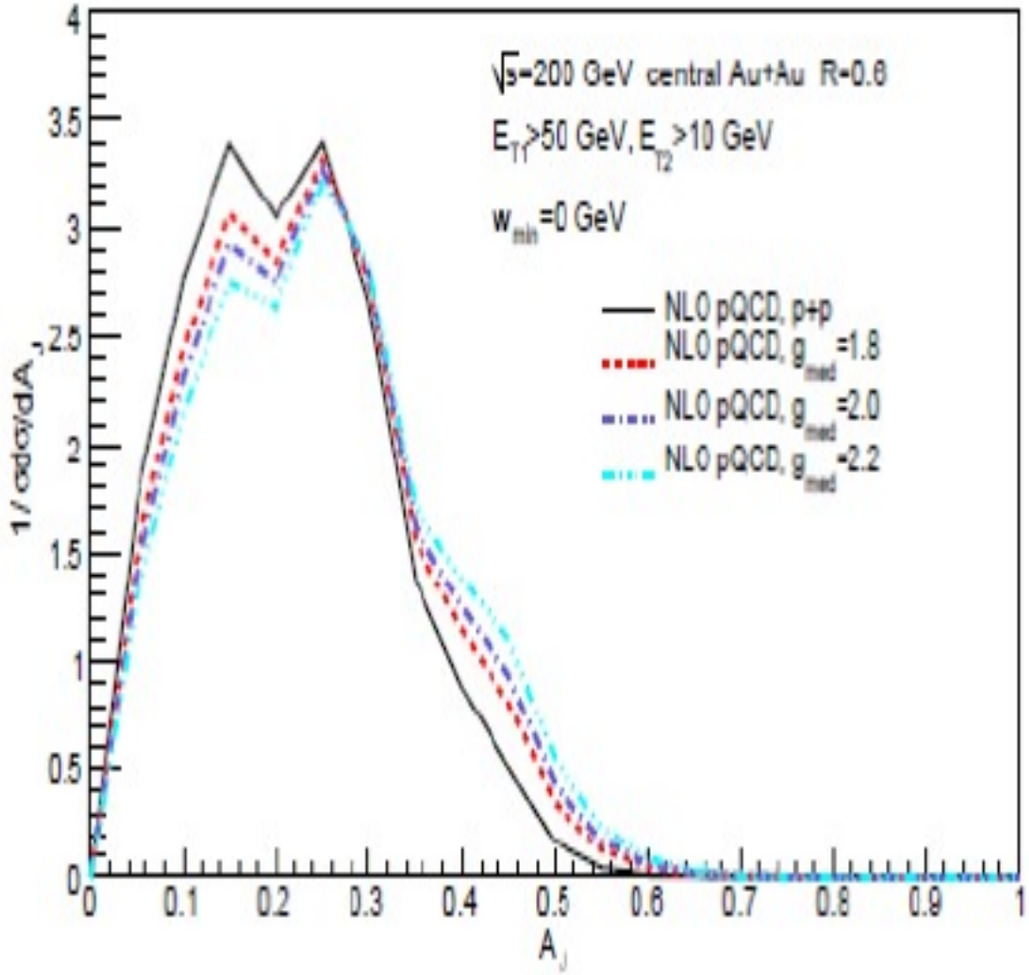


symmetric ⟷ asymmetric

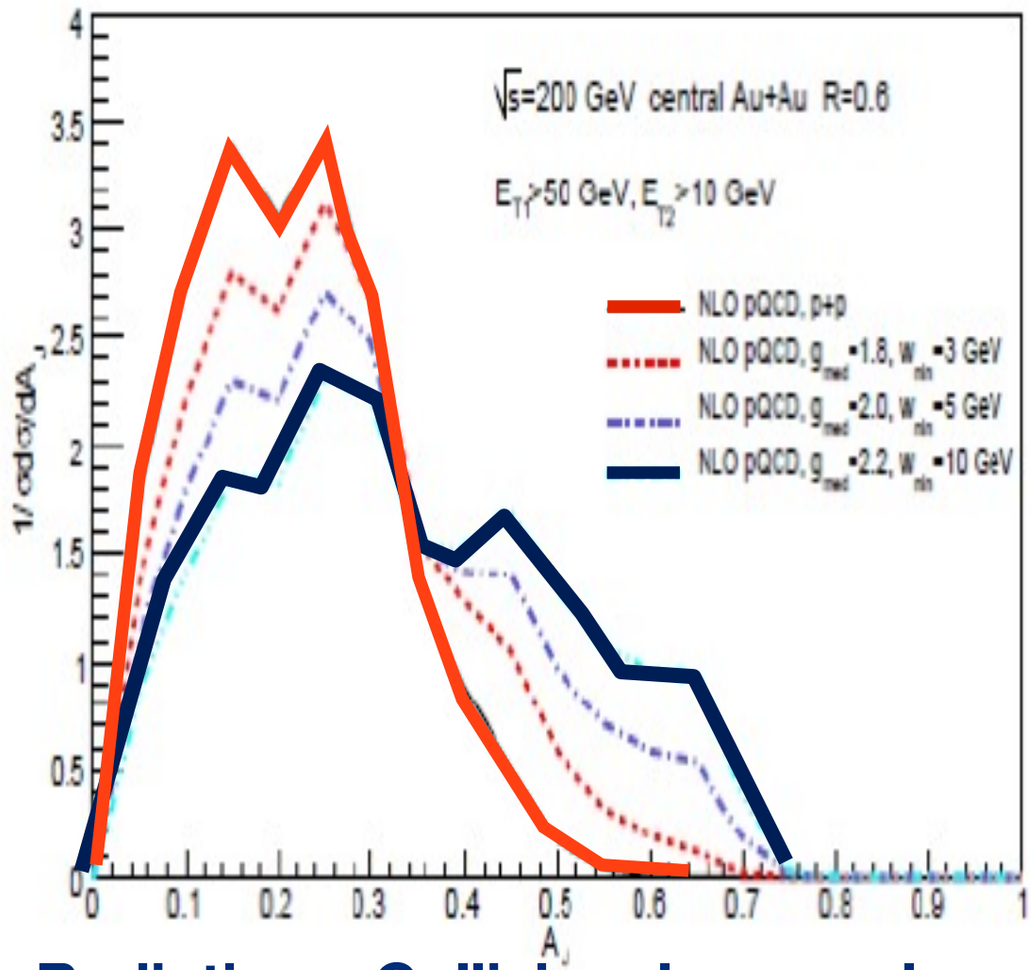
Chris Coleman-Smith (Duke)

Radiative and collisional energy loss

What are the effective constituents of the QGP?



Radiative energy loss only

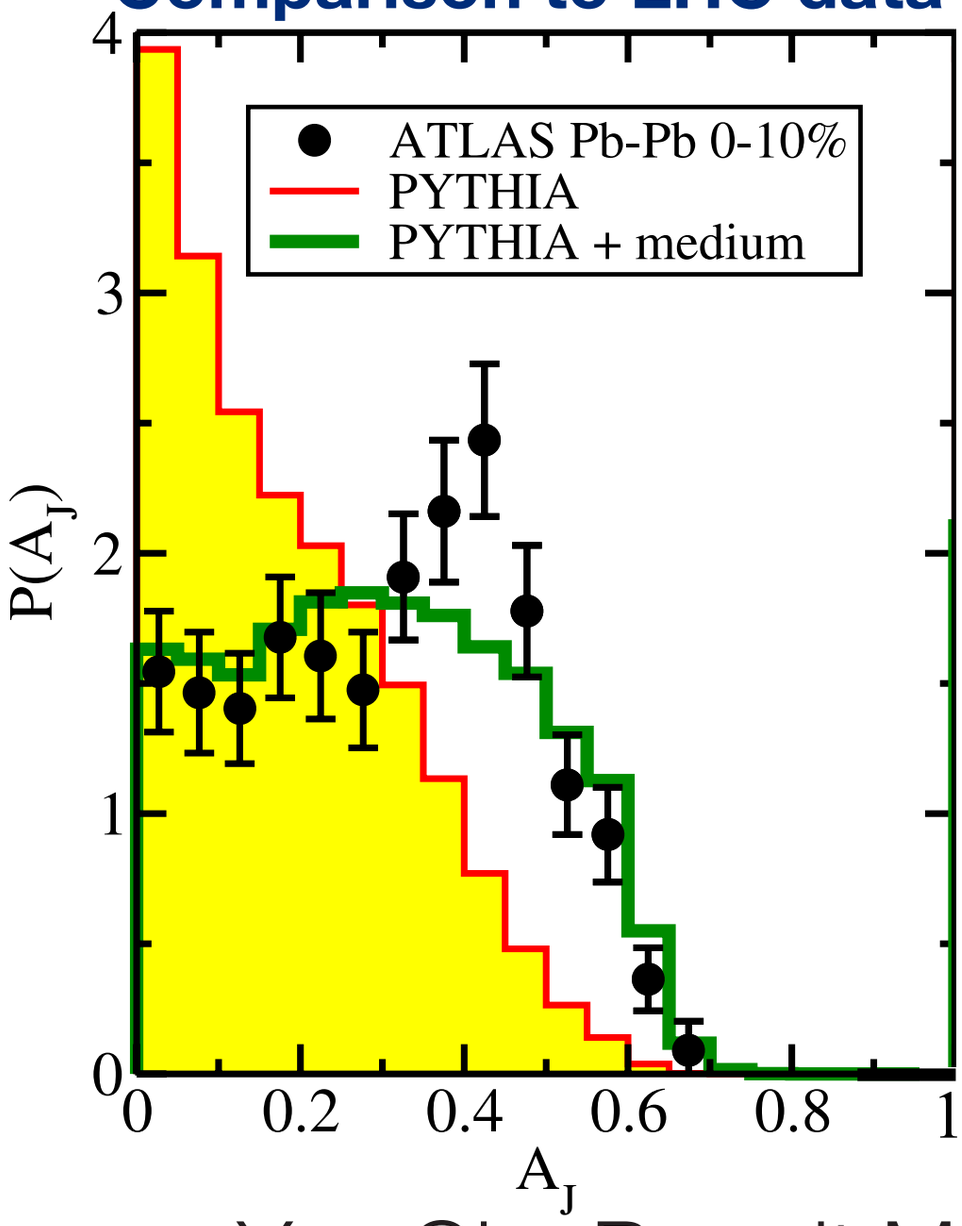


Radiative + Collisional energy loss
±10% changes in coupling strength

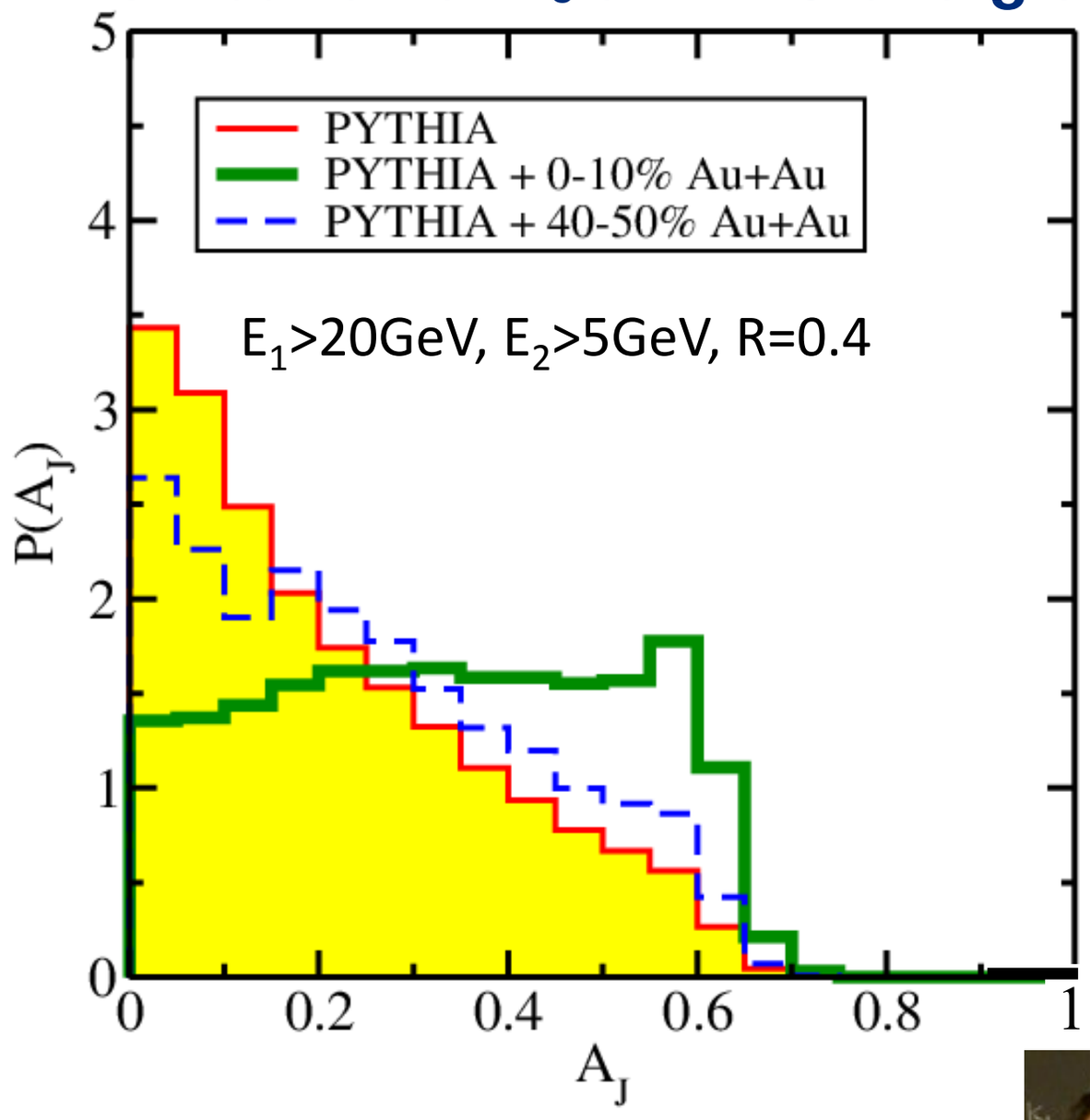
Ivan Vitev, *et al*

Interaction of jet with medium

Comparison to LHC data

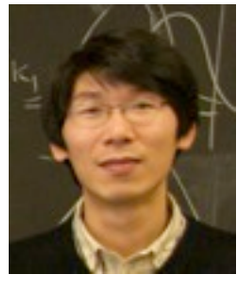


Distribution of A_J at RHIC energies

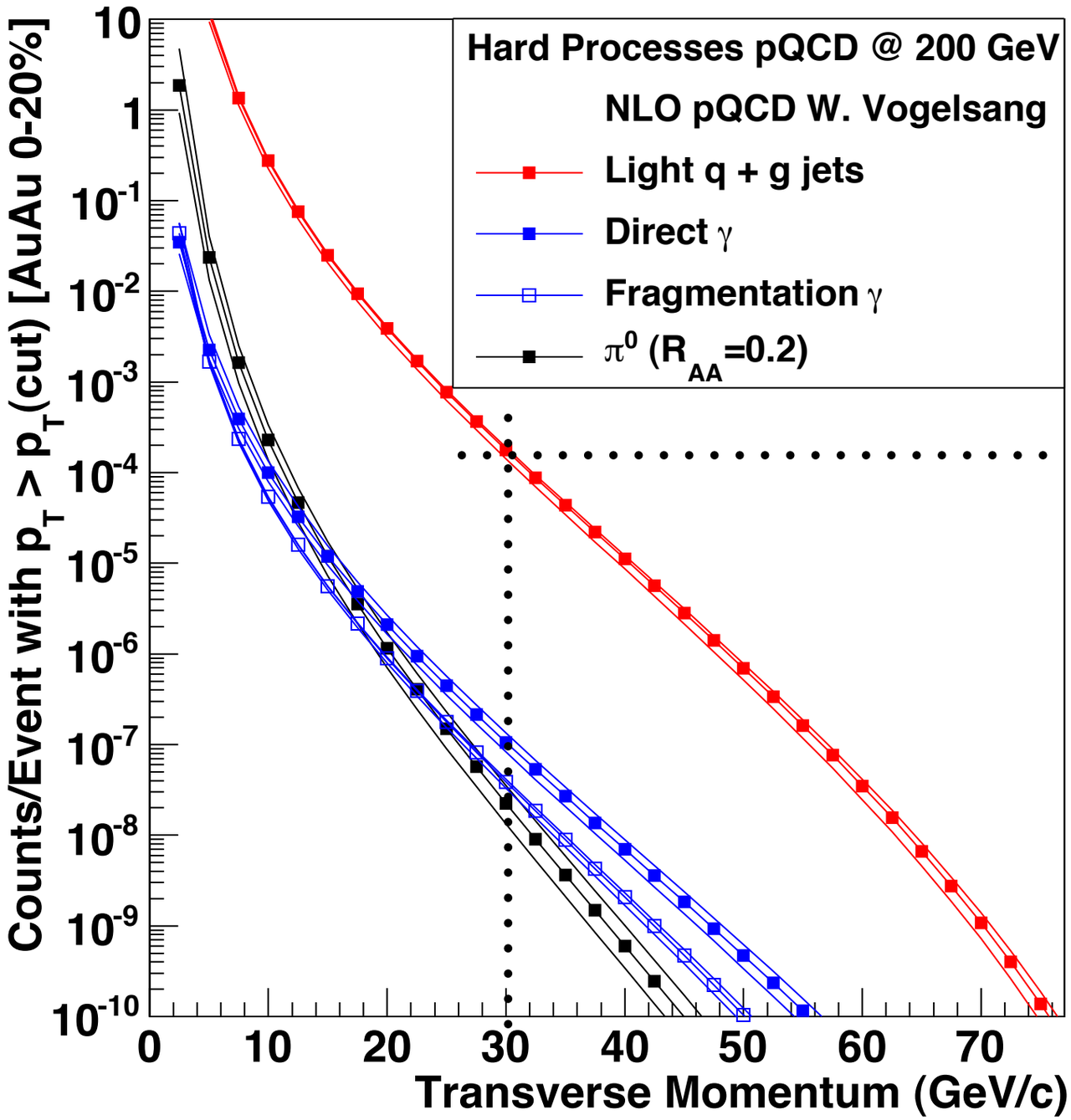


Guang-You Qin, Berndt Muller

PRL 106, 162302 (2011)



Jet rates in Au+Au at RHIC



counts/year

10^9

10^6

10^3

1

There *are lots* of jets!

Only stochastic cooling of Au beams assumed

Greater rate and p_T reach than singles

1 RHIC year = 50 billion min. bias Au+Au events = 10 billion central

Expected counts in a 20 week run

	Au+Au central 20%	p+p	d+Au
>20 GeV	10^7 jets 10^4 photons	10^6 jets 10^3 photons	10^7 jets 10^4 photons
>30 GeV	10^6 jets 10^3 photons	10^5 jets 10^2 photons	10^6 jets 10^3 photons
>40 GeV	10^5 jets	10^4 jets	10^5 jets
>50 GeV	10^4 jets	10^3 jets	10^4 jets

Huge rates allow differential measurements <u>with</u> geometry

(v_2, v_3, A+B, U+U, …)

precise control measurements (d+Au & p+p).

Over 80% as dijets into $|\eta|<1$

Cu+Au ~ Au+Au/5

U+U (tip-tip) ~ Au+Au/500

Are jets in HI at RHIC dominated by *fakes*?

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Jet - Underlying Event Separation Method for Heavy Ion Collisions at the Relativistic Heavy Ion Collider

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[1] *Department of Physics and Astronomy, Stony Brook University, SUNY, Stony Brook, New York 11794-3400, USA*
[2] *Physics Department, Brookhaven National Laboratory, Upton, New York, 11973-5000*
[3] *Columbia University, New York, New York 10027 and Nevis Laboratories, Irvington, New York 10533, USA and*
[4] *University of Colorado, Boulder, Colorado 80309, USA*
(Dated: March 8, 2012)

arXiv:1203.1353

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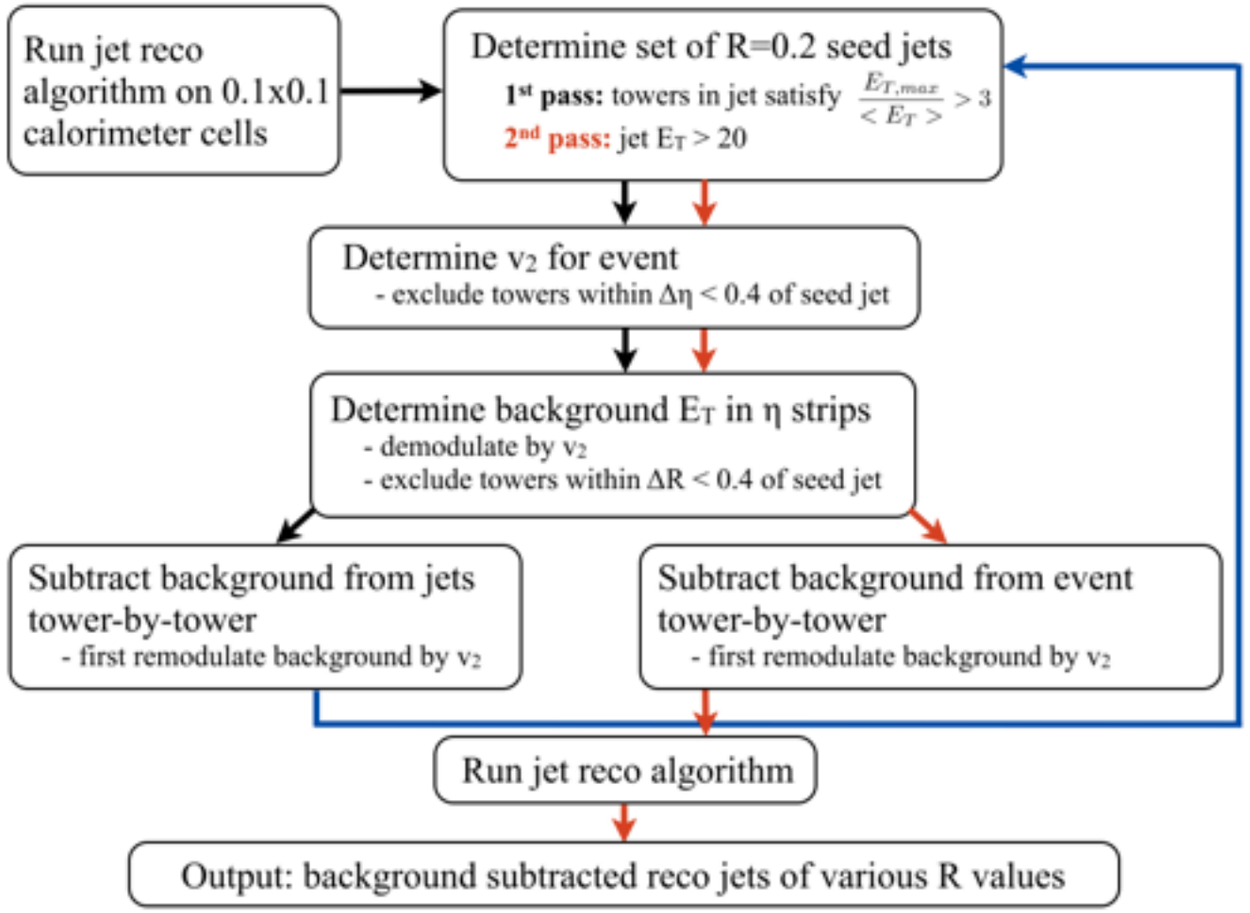
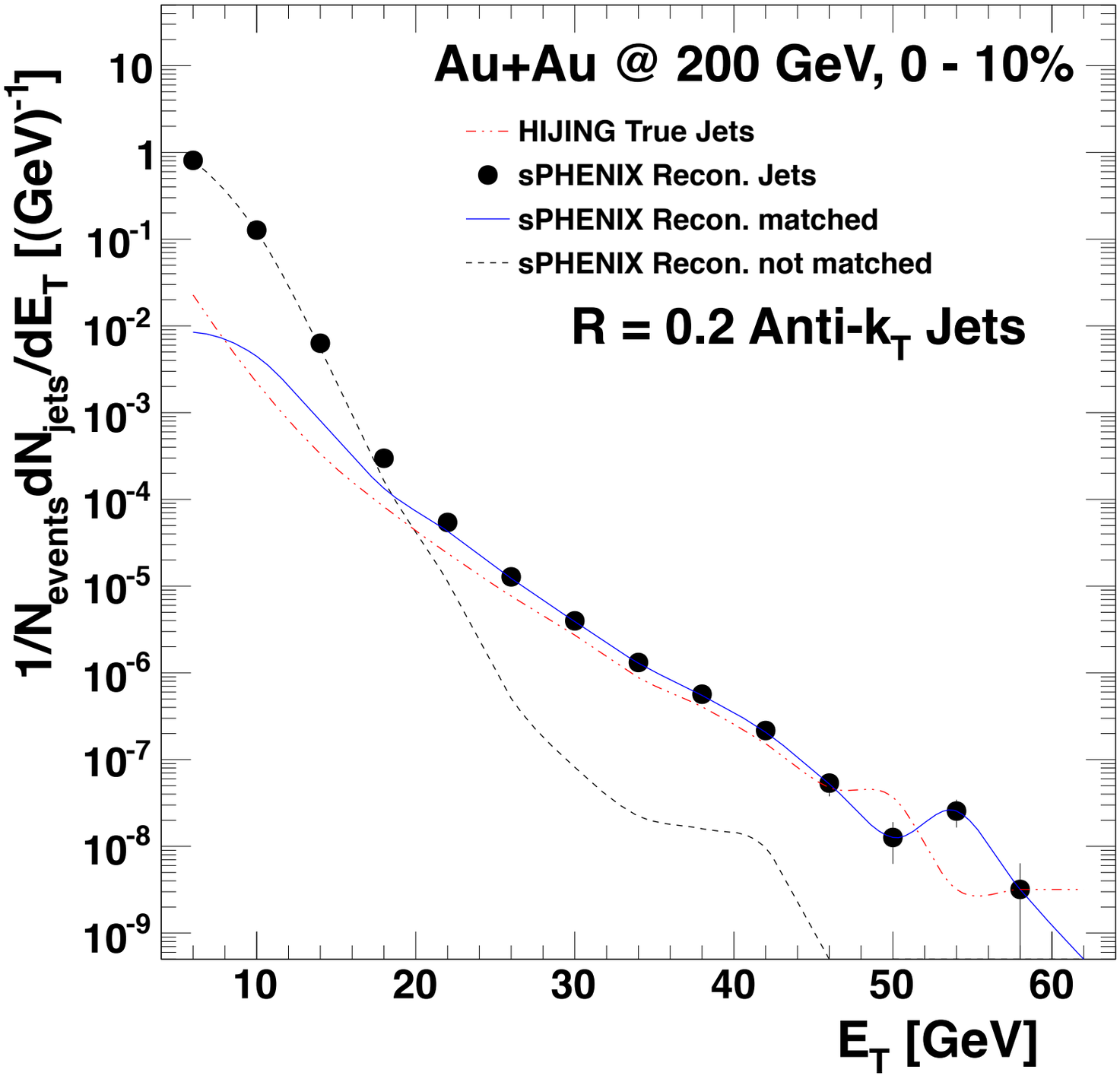
Over *1 billion* HIJING events run, tagging of fragmentation call jets, with full "ATLAS style" background subtraction method employed



Clean jets above an R-dependent E_T lower bound



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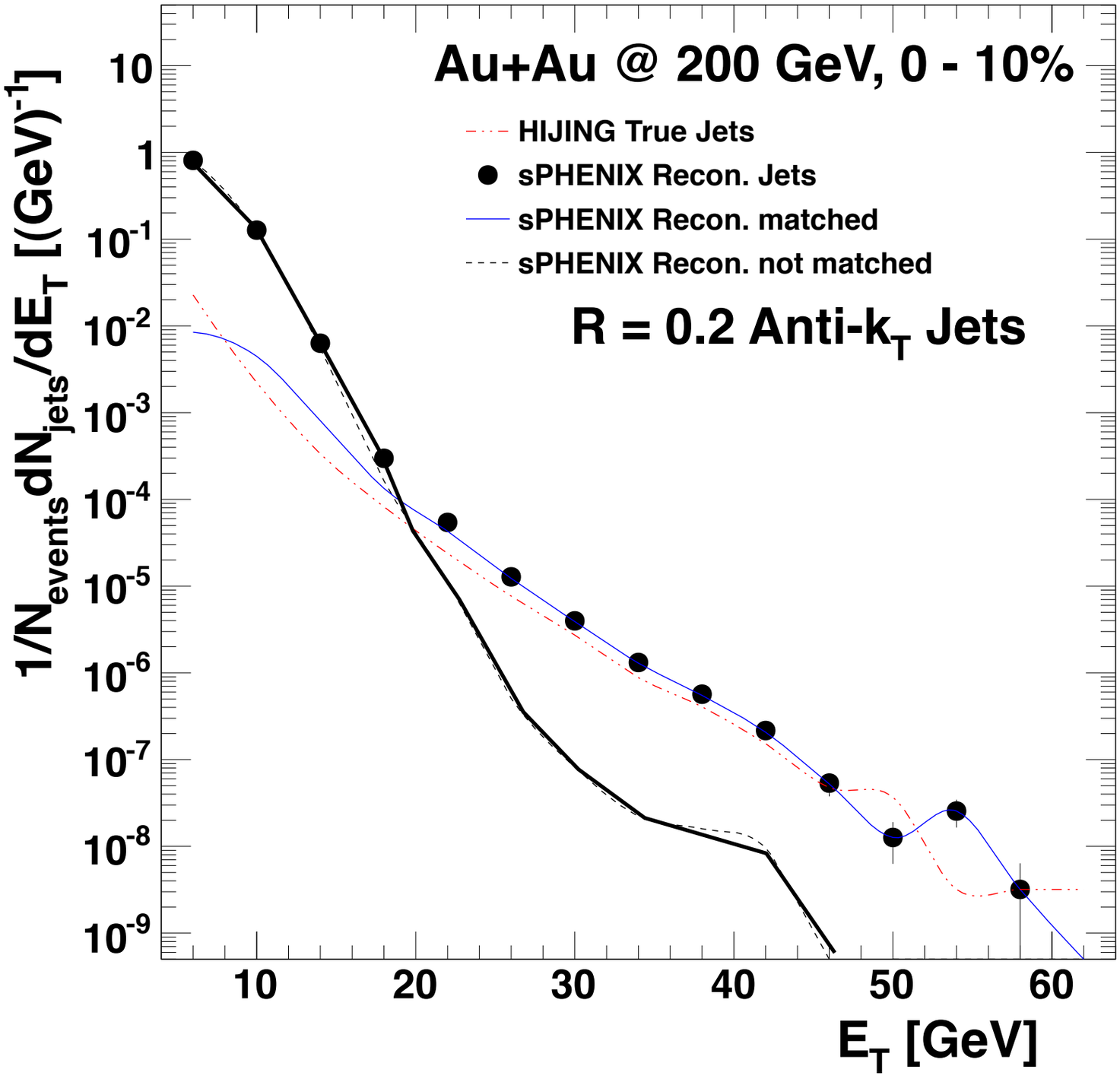

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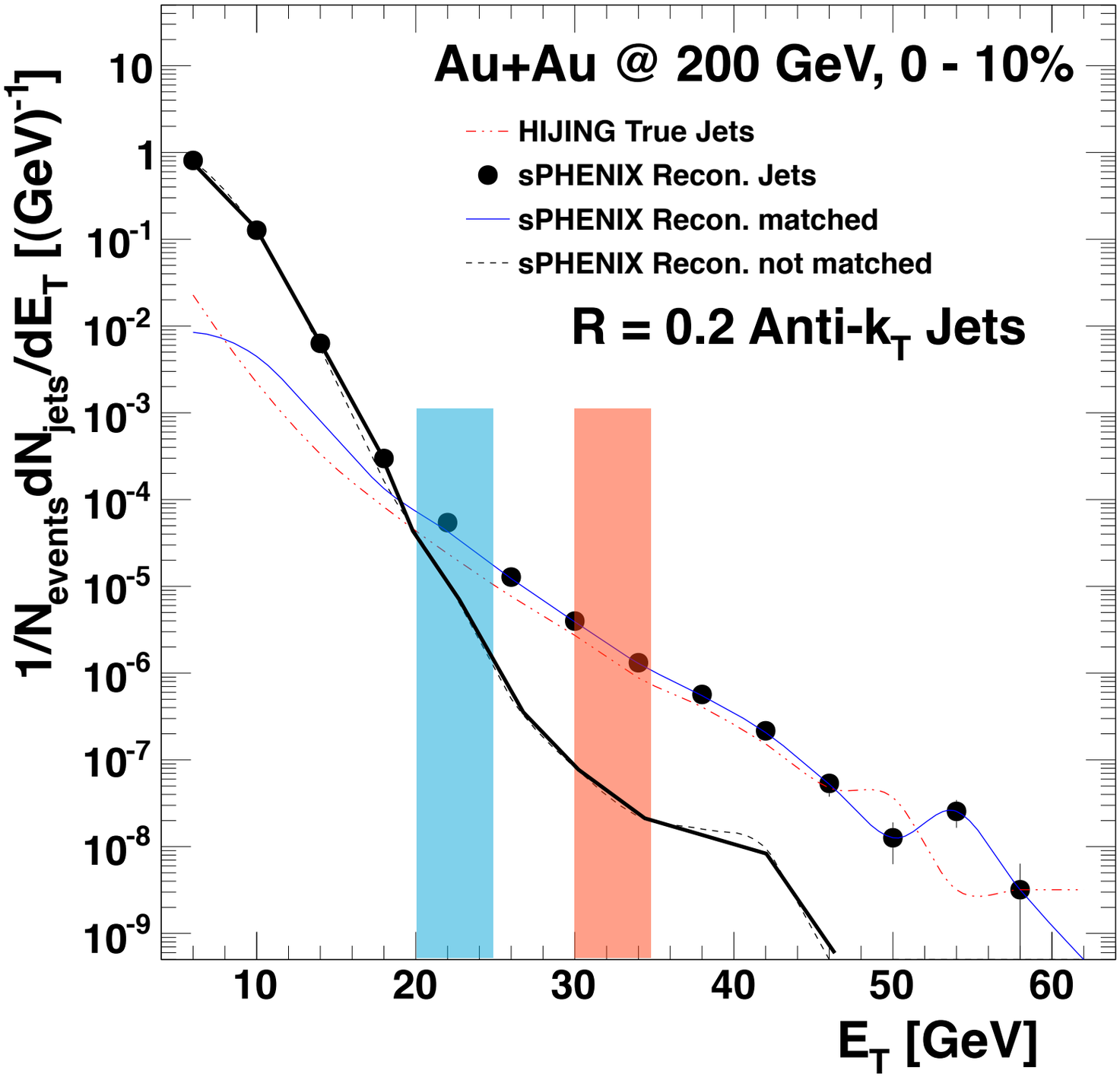
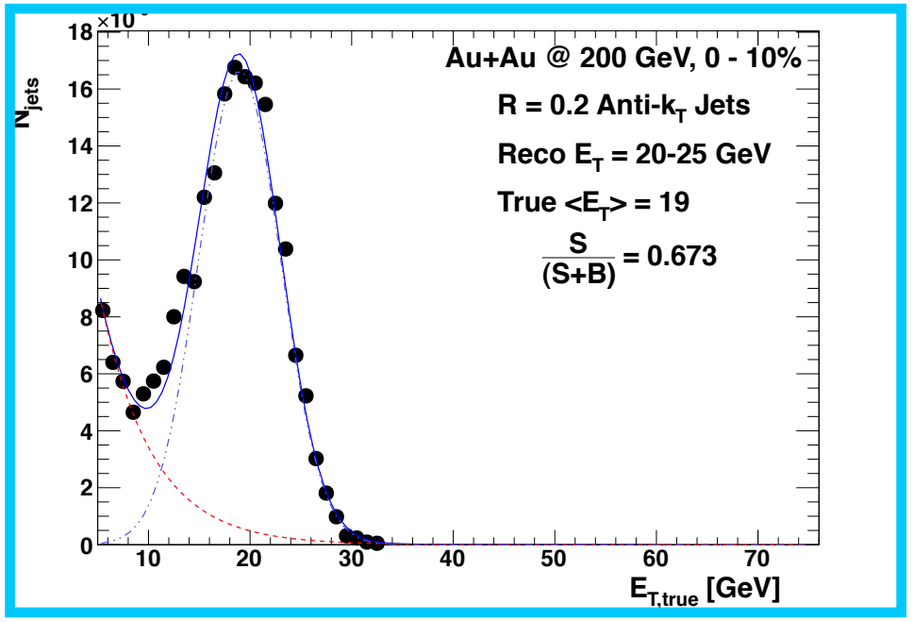
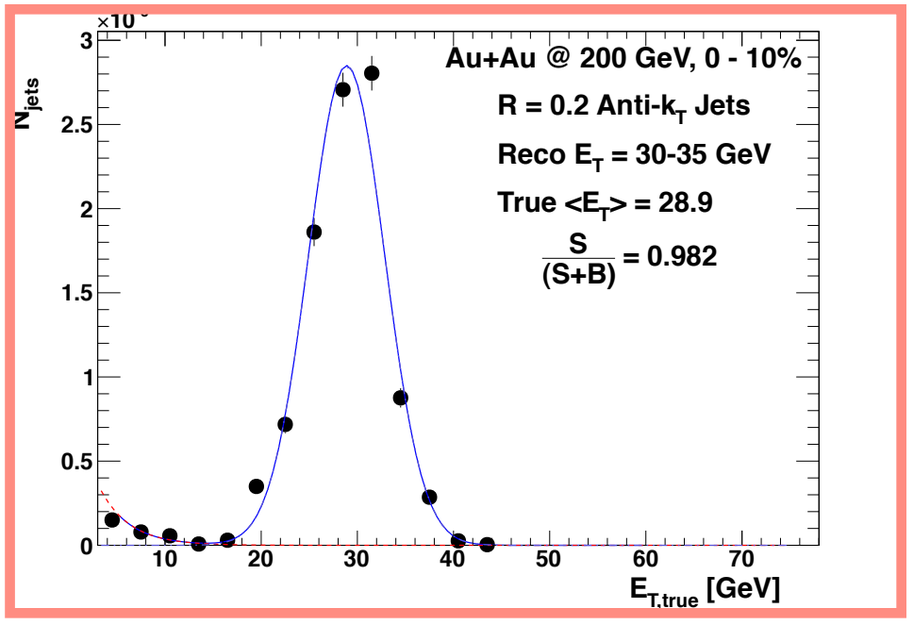
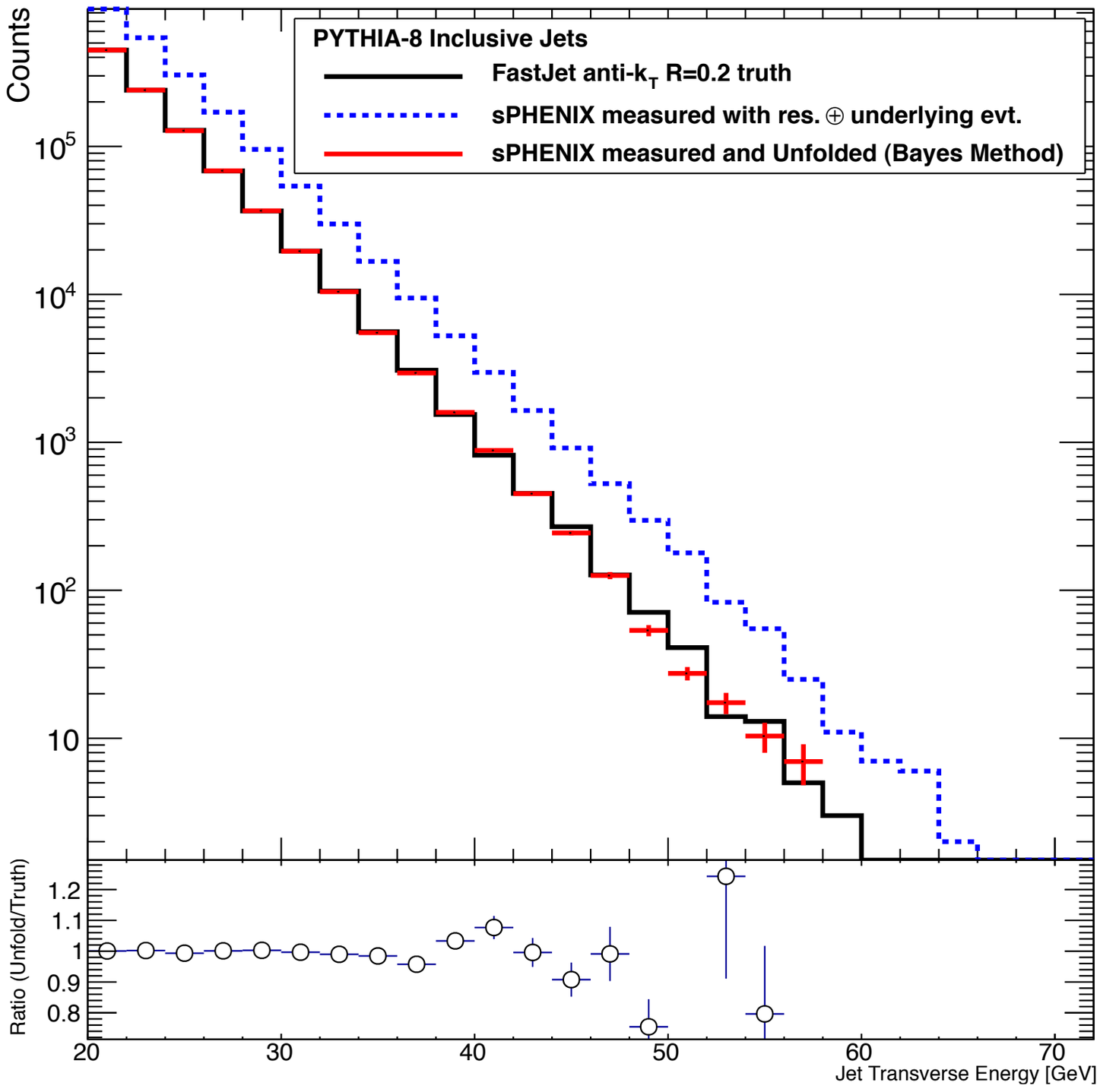






Unfolding the effects of detector smearing



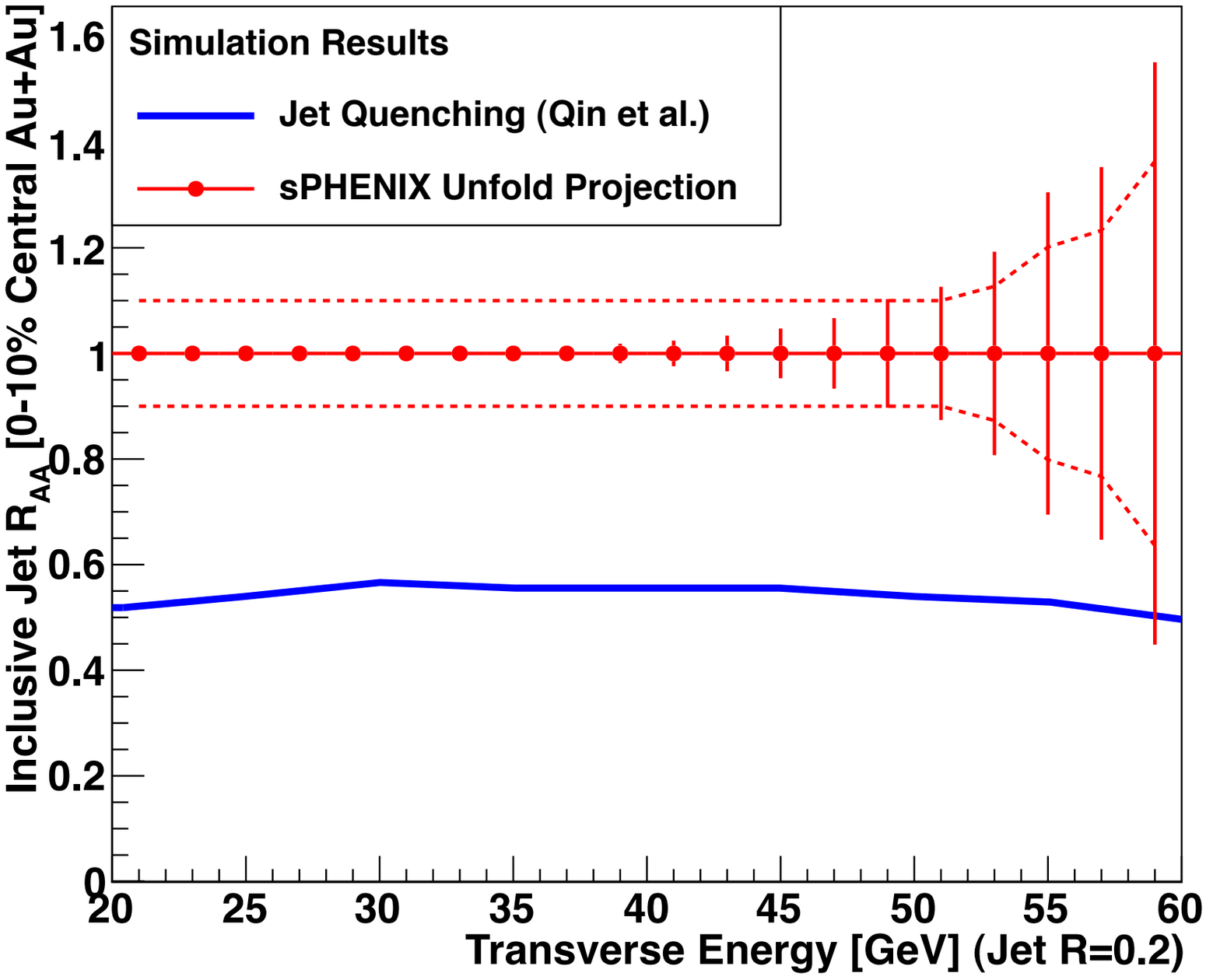
PYTHIA jets plus underlying central Au+Au event plus detector smearing

use ROOUNFOLD Iterative Bayes' method

recovers truth spectrum

jet R_{AA} to high p_T possible

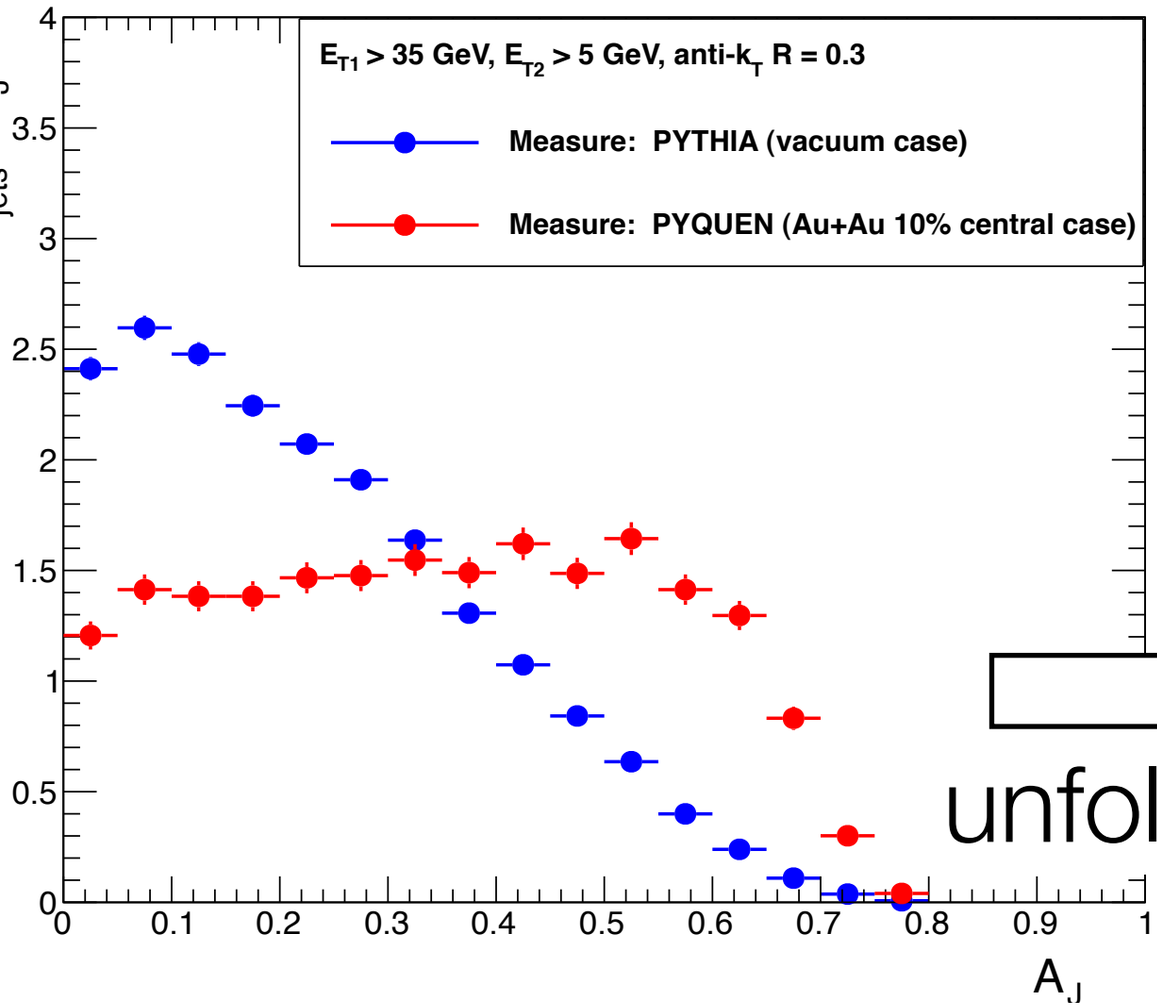
Jet R_{AA} to high p_T



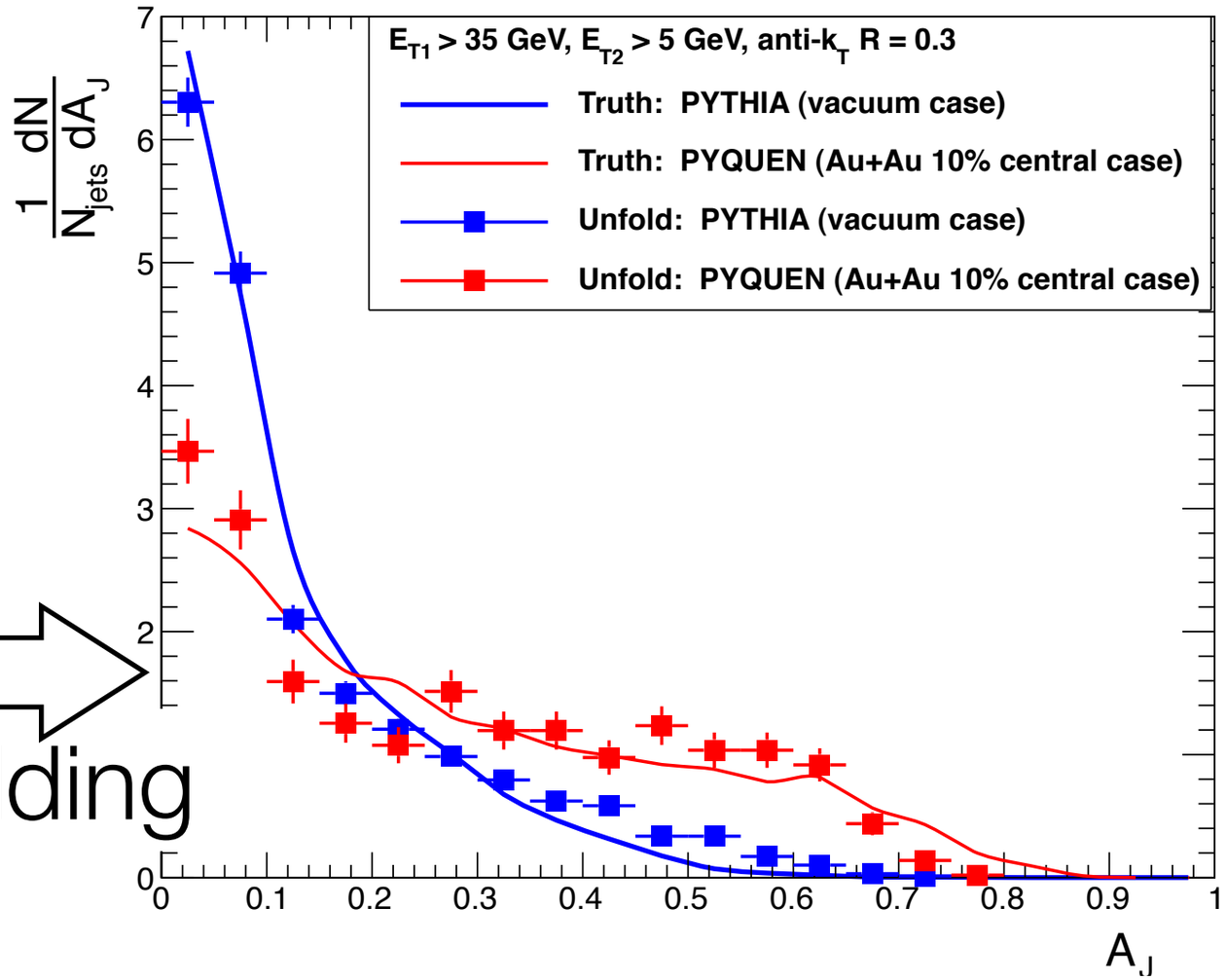
Guang-You Qin, private communication

Dijet asymmetry in central Au+Au at RHIC

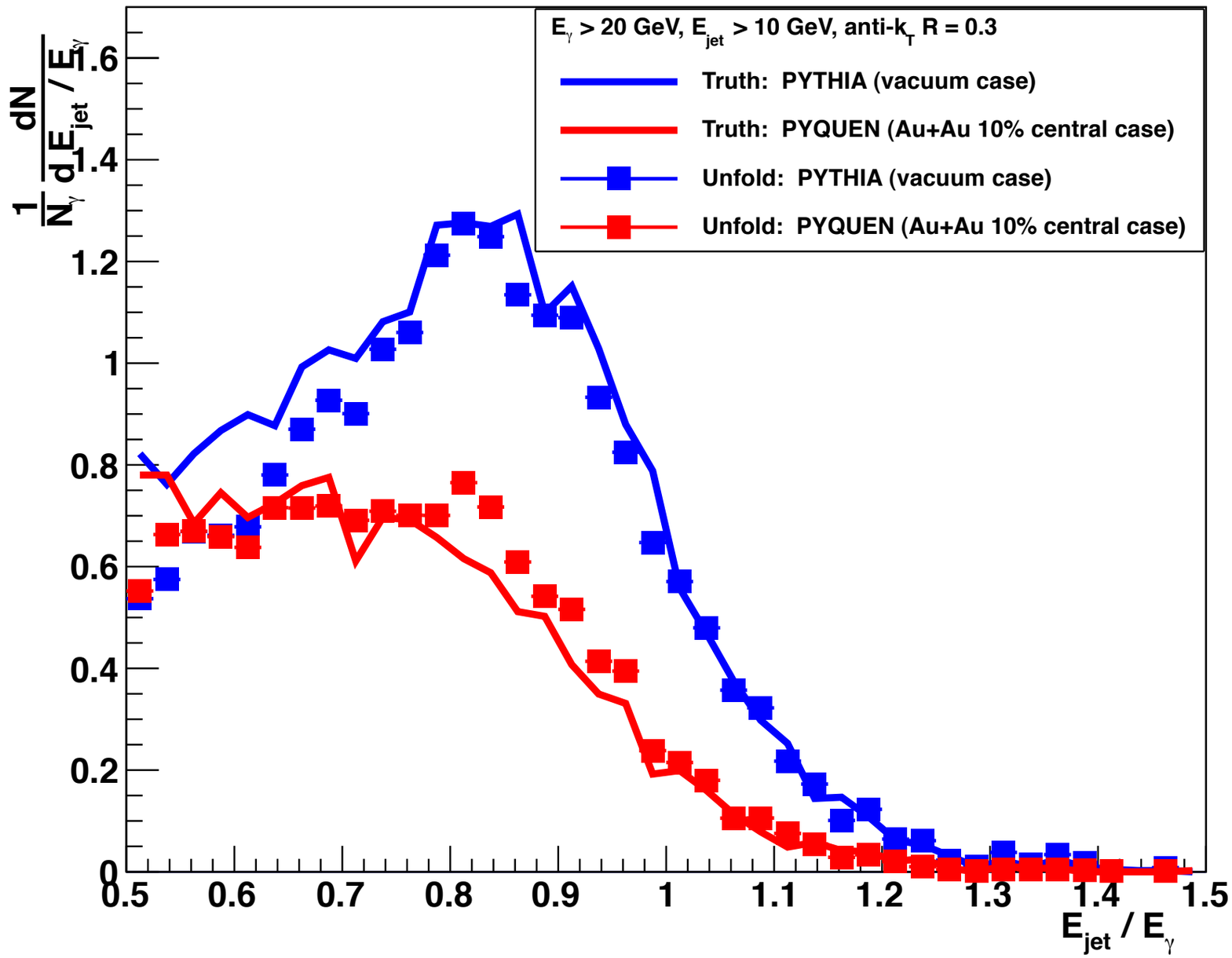
Clean trigger jet above 35 GeV ⇒ away side clean down to 5 GeV

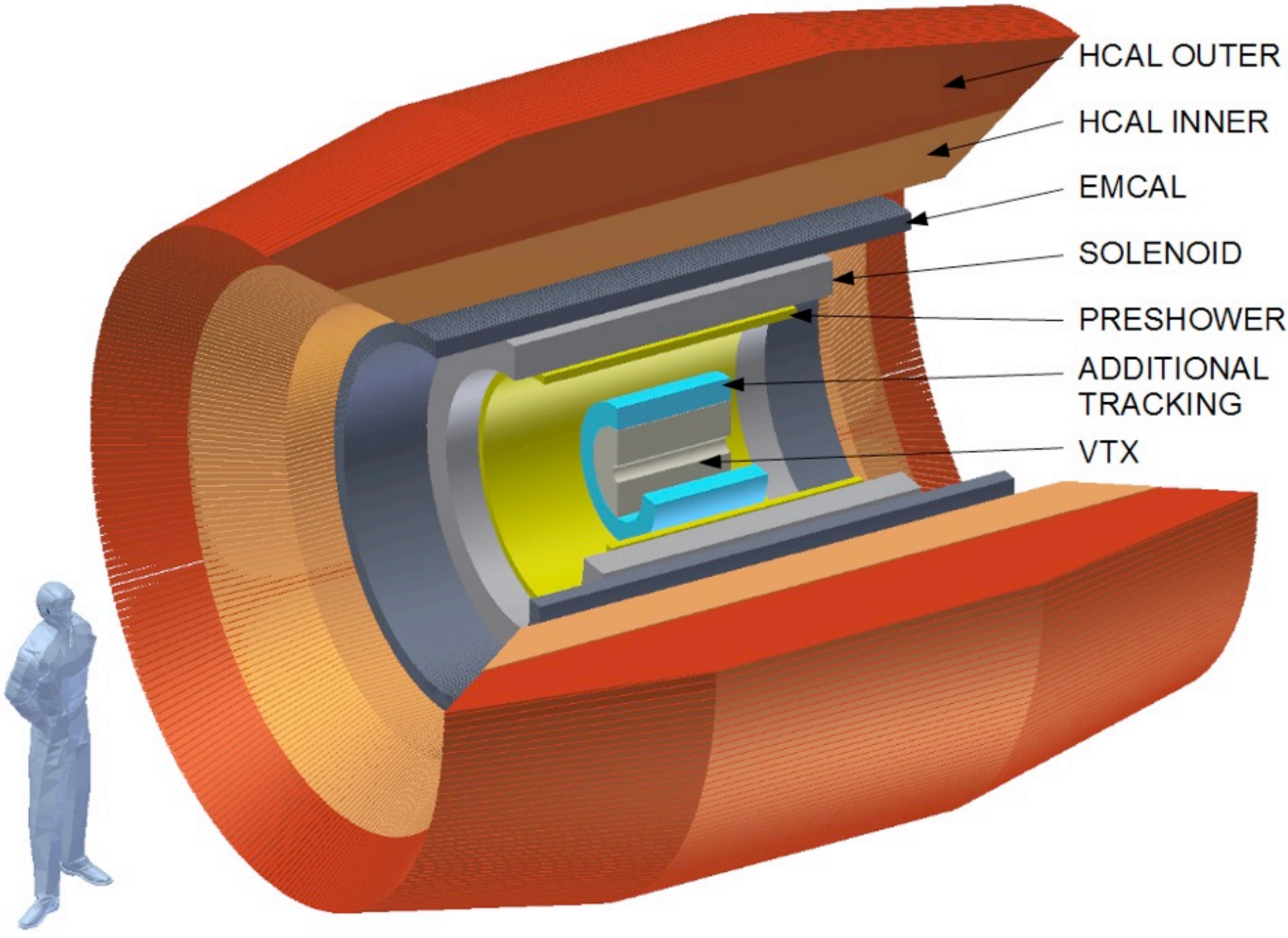


unfolding

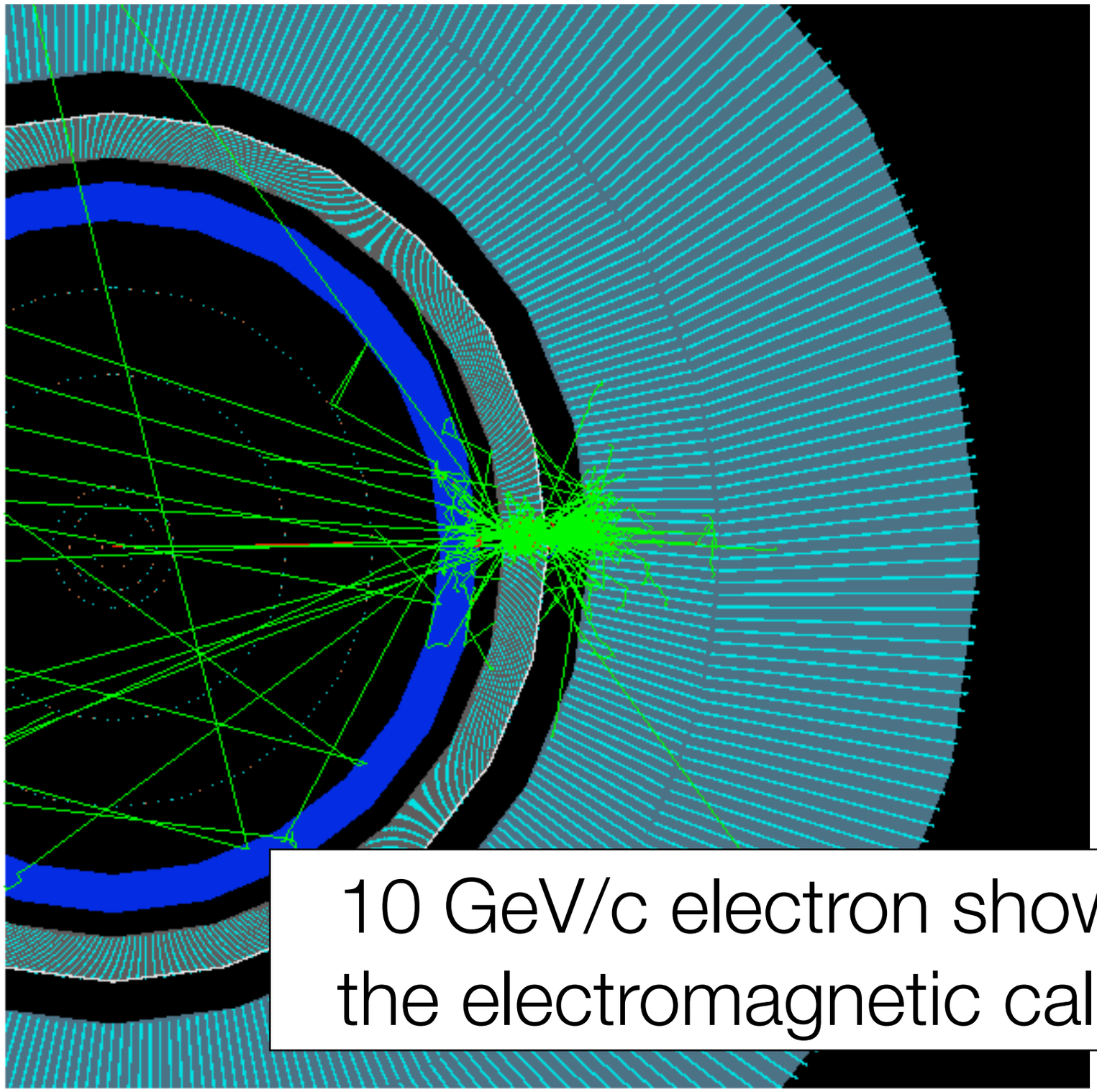


Unfolded γ+jet energy ratio in central Au+Au



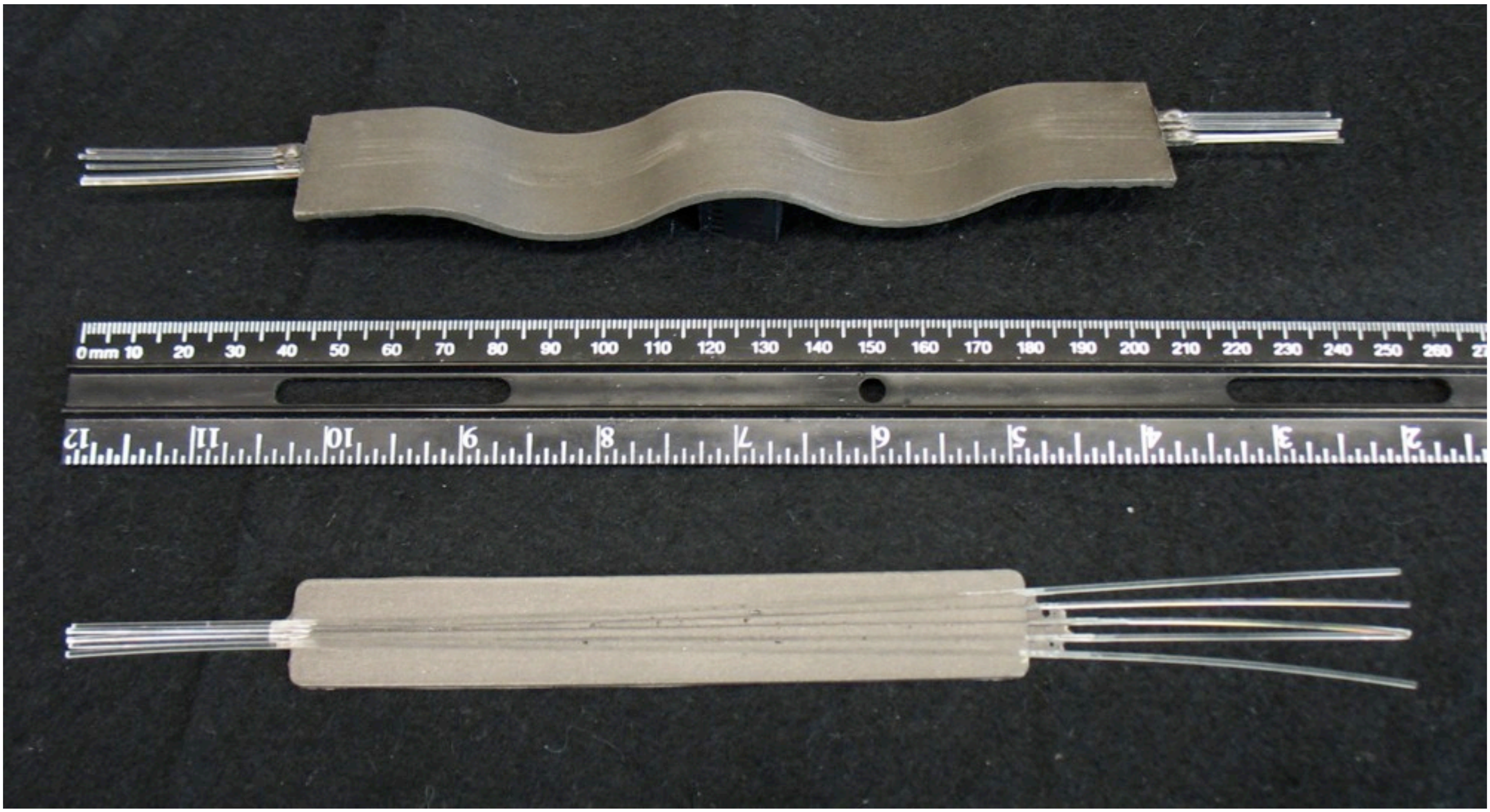

HCAL OUTER
HCAL INNER
EMCAL
SOLENOID
PRESHOWER
ADDITIONAL TRACKING
VTX

Full GEANT4 simulation



10 GeV/c electron showering in the electromagnetic calorimeter

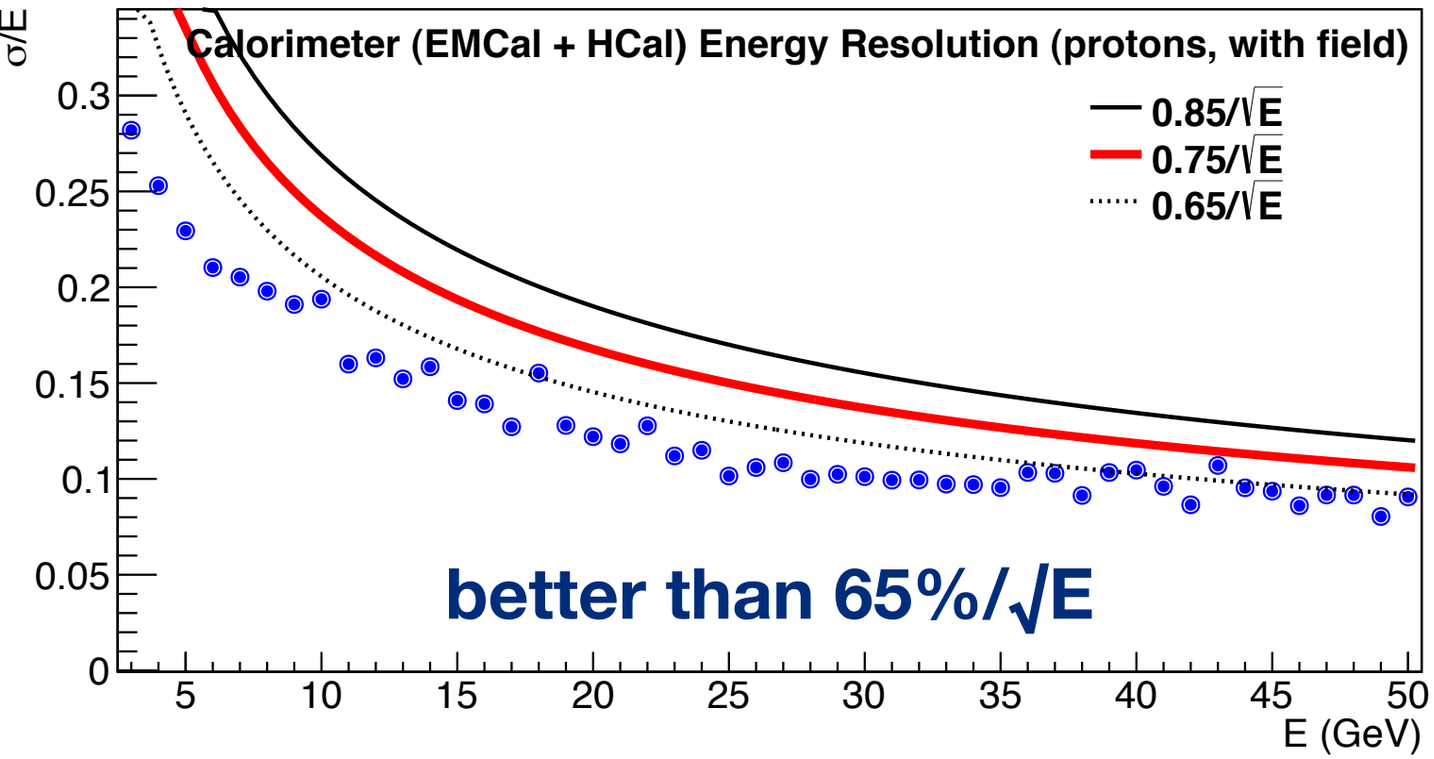
Major technological advances: tungsten + SiPMs



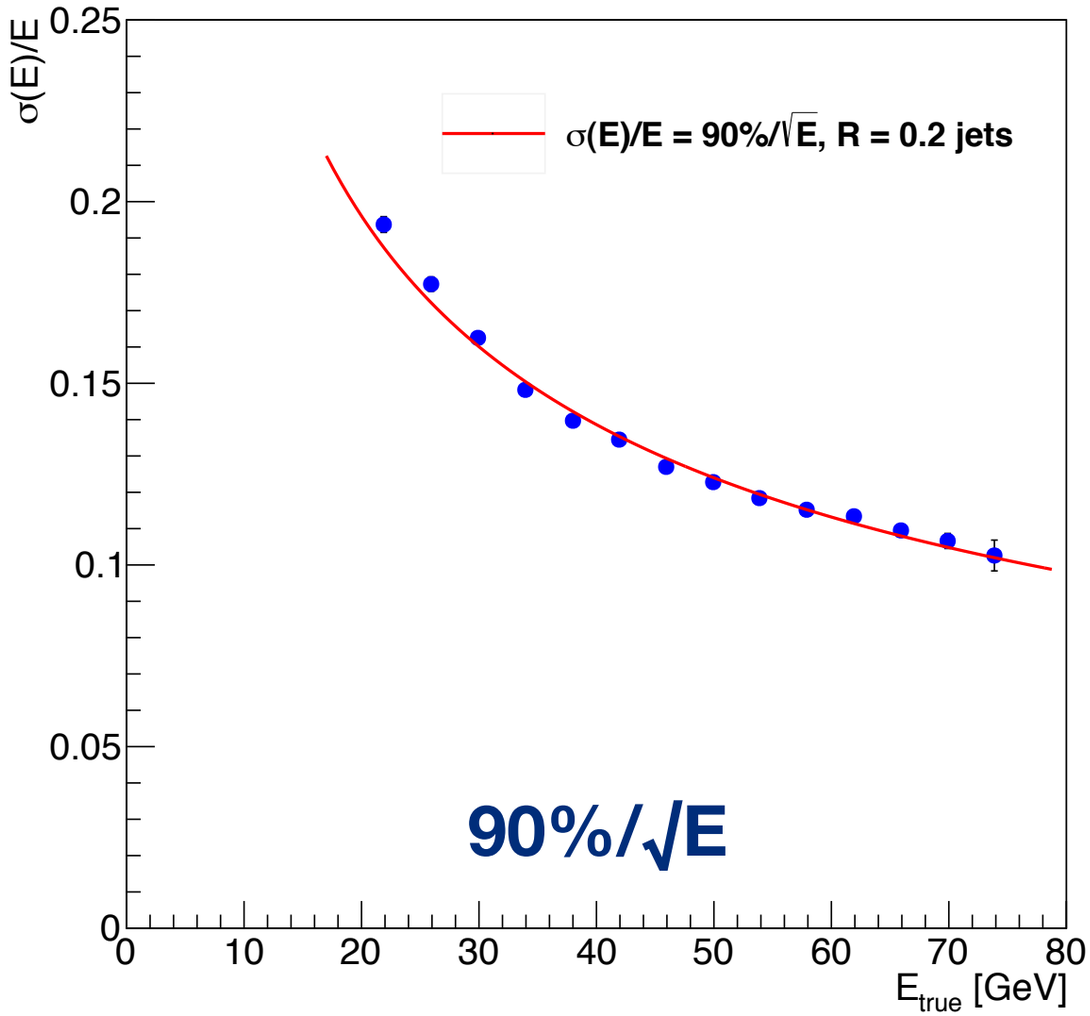
formed tungsten+epoxy with embedded fibers

How well would this new technology work?

Single particle resolution in EMCal+HCal



Jet energy resolution from full GEANT4 in *p+p*



Consistent with experience that jet resolution in p+p ~ 1.2–1.3x HCal resolution.

jet resolution in HI ~ 1.6x HCal

high rate calorimetric jet measurements at RHIC

- jets, dijets, γ–jets
- other very interesting possibilities: jet v_N, jet–hadron correlations
- heavy quark jets: requires additional tracking beyond VTX (expressions of interest from Japanese RIKEN)
- variety of systems for control of initial state effects and geometry

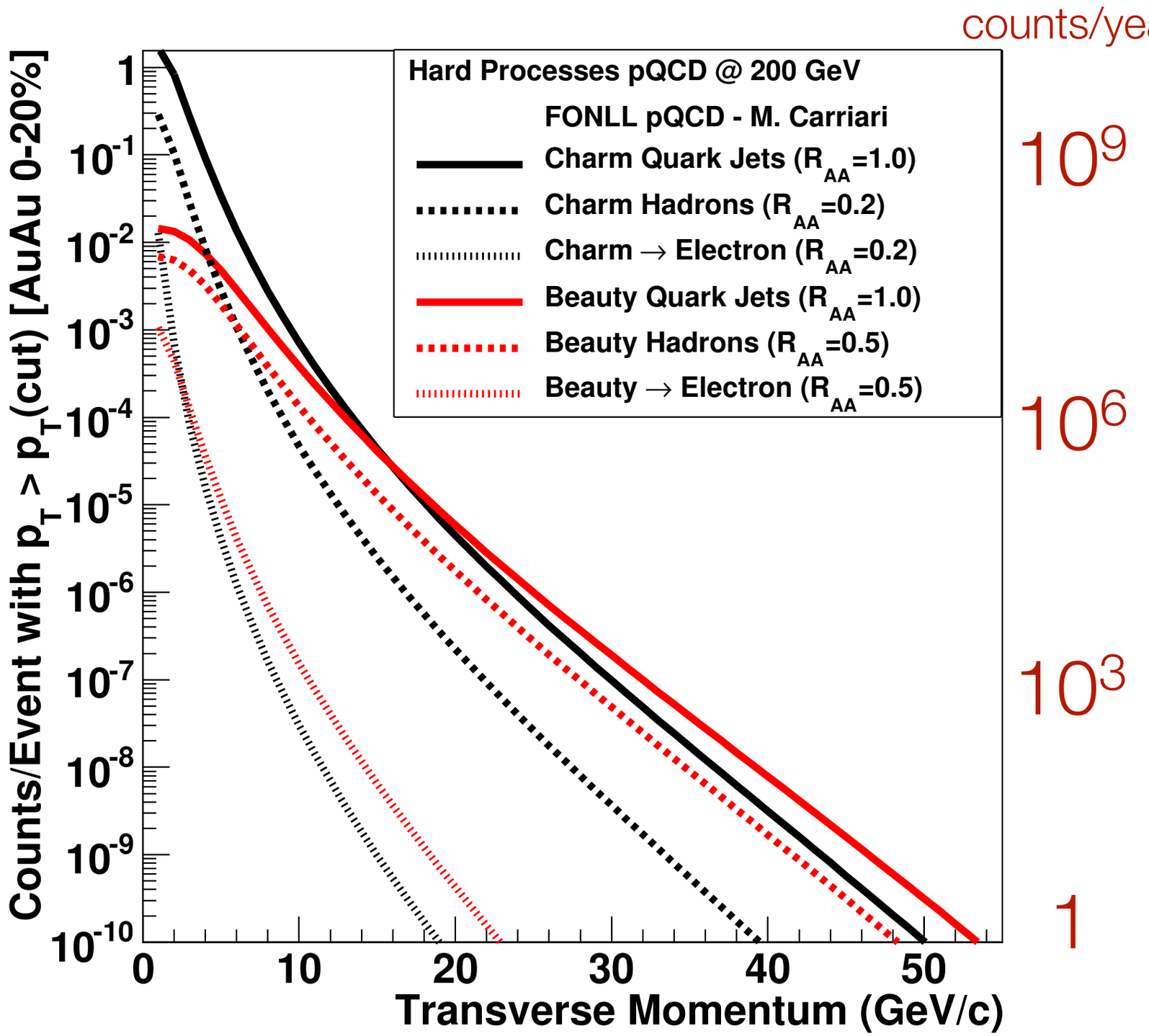
together with LHC constrain physics of energy loss

novel detector concept

- exploits recent technological advances
- staged approach includes forward spin + p+A program
- sPHENIX has path to evolve into EIC ePHENIX

Extra slides

Heavy-flavor tagged jets (requires add'l tracking)



counts/year

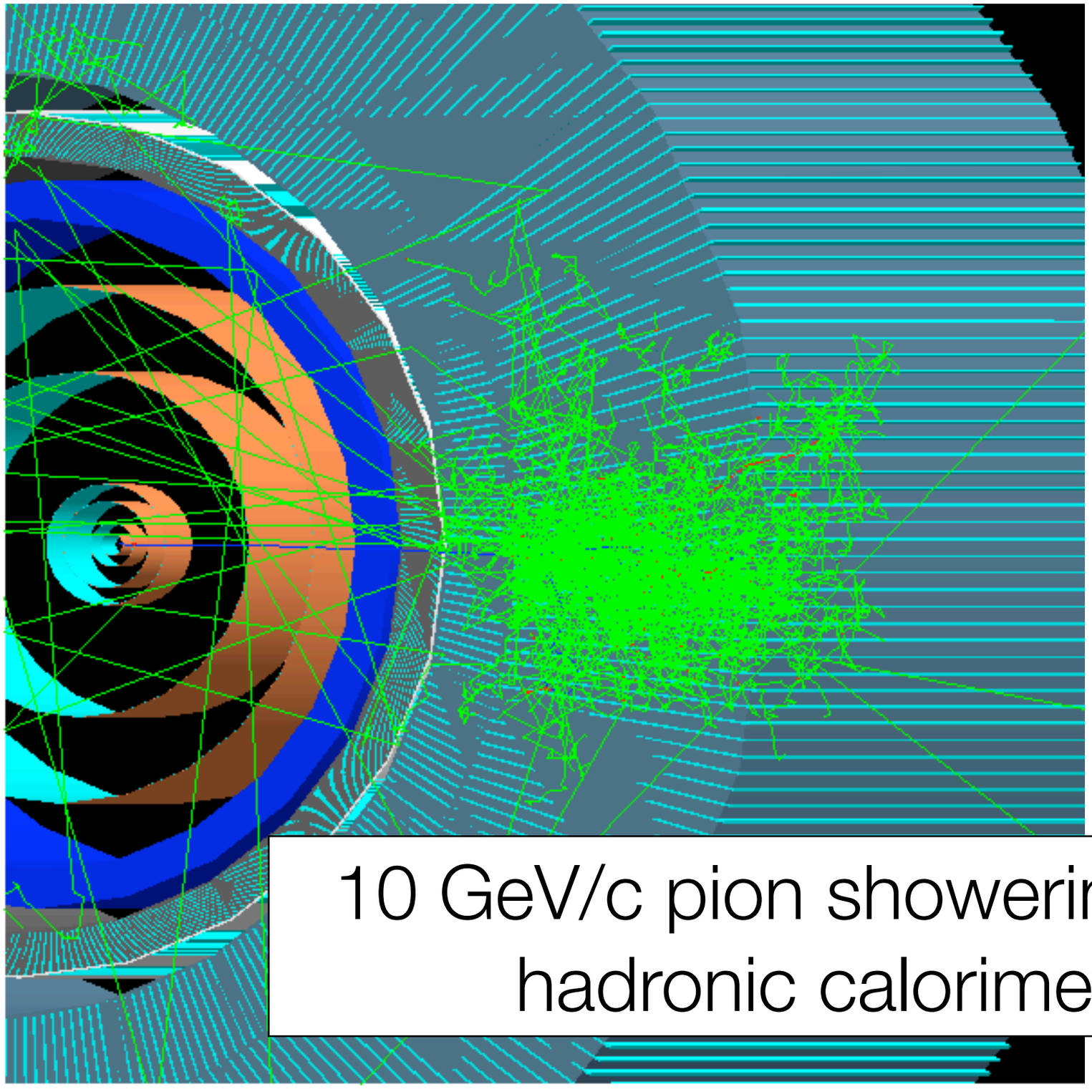
10^9

10^6

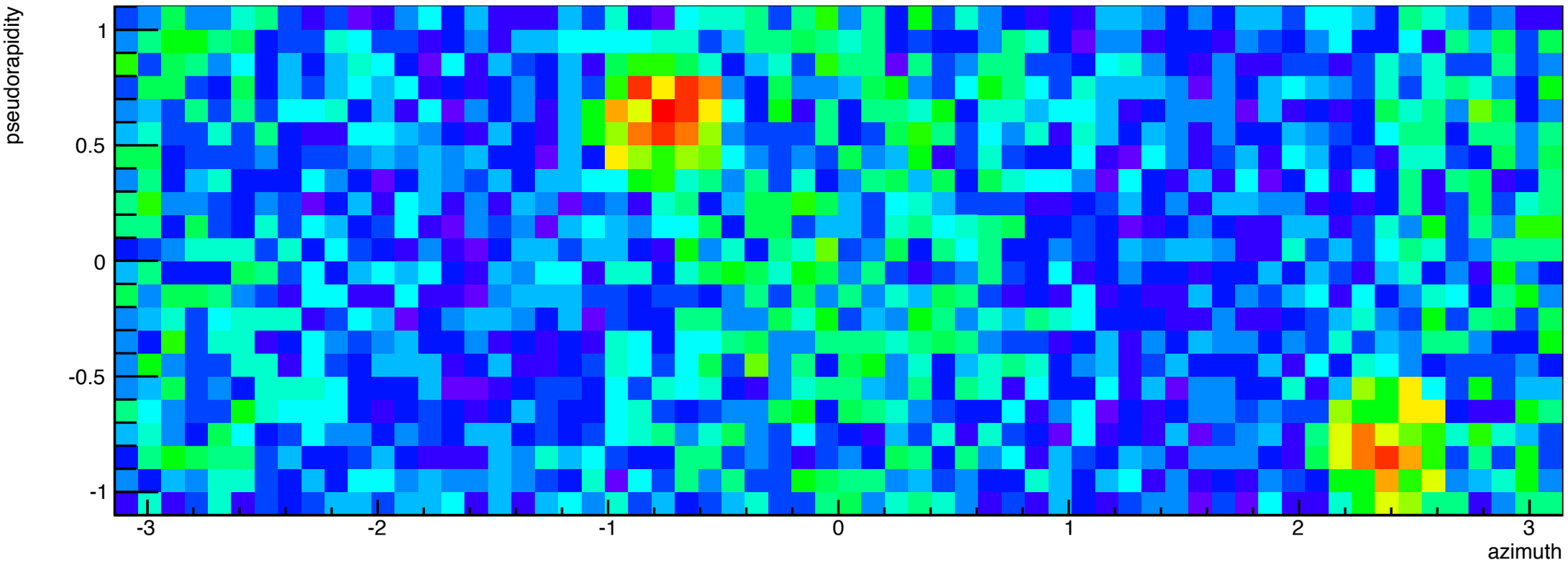
10^3

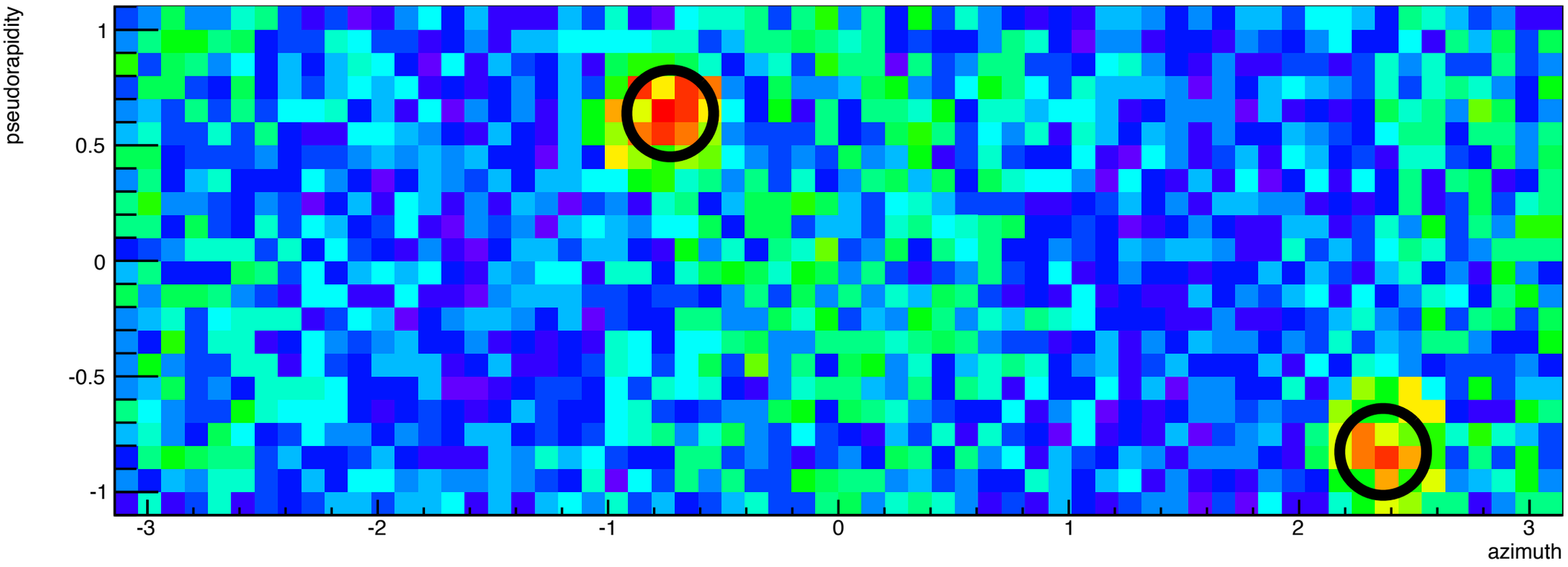
1

Full GEANT4 simulation



10 GeV/c pion showering in the hadronic calorimeter


pseudorapidity
1
0.5
0
-0.5
-1
-3
-2
-1
0
1
2
3
azimuth


pseudorapidity
1
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0
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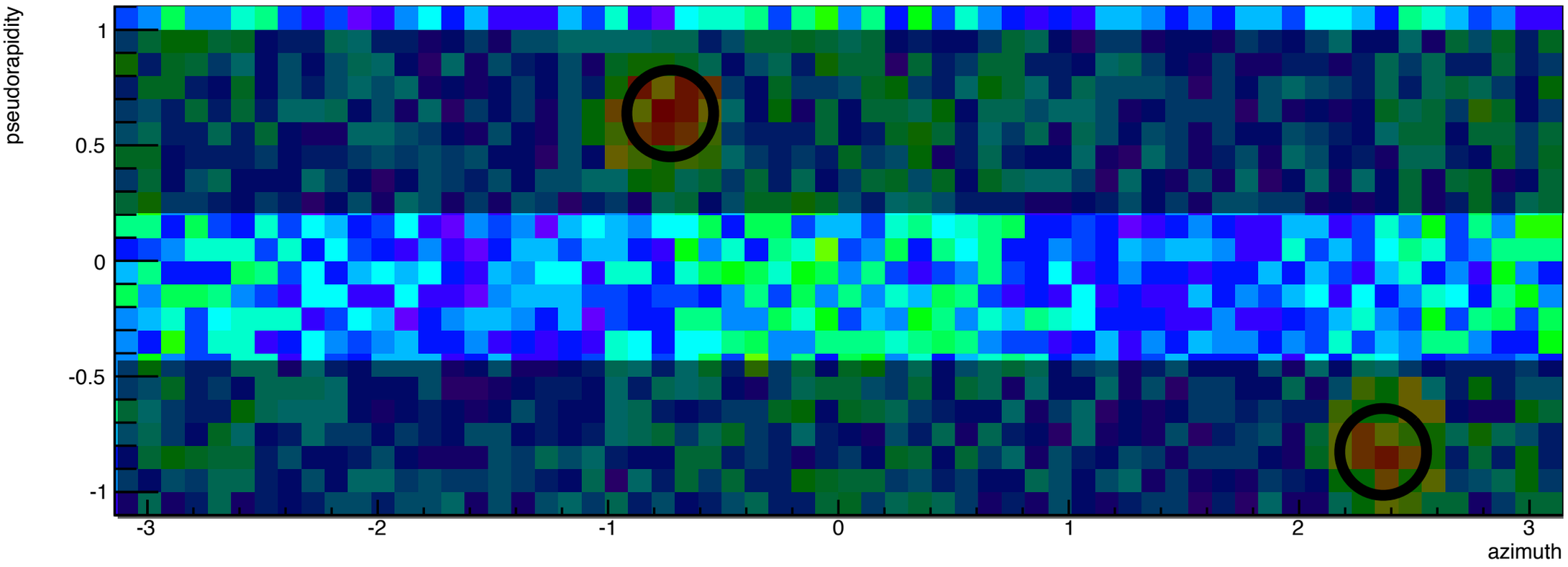
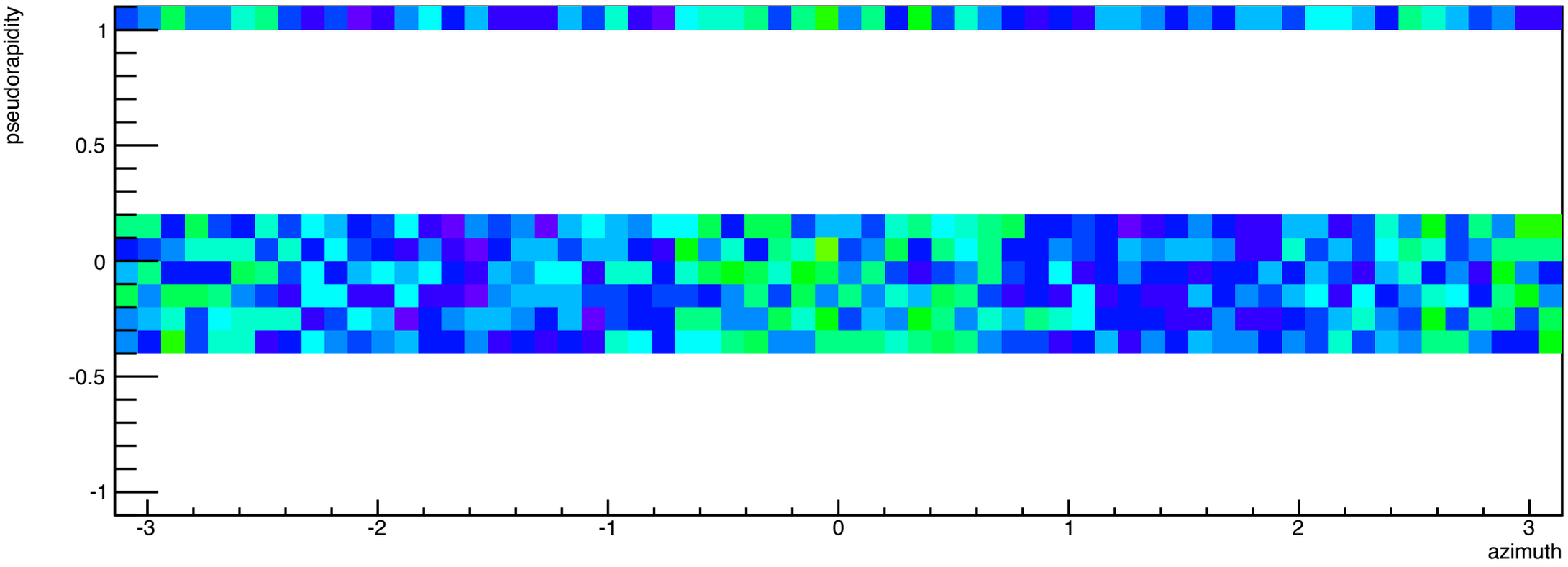
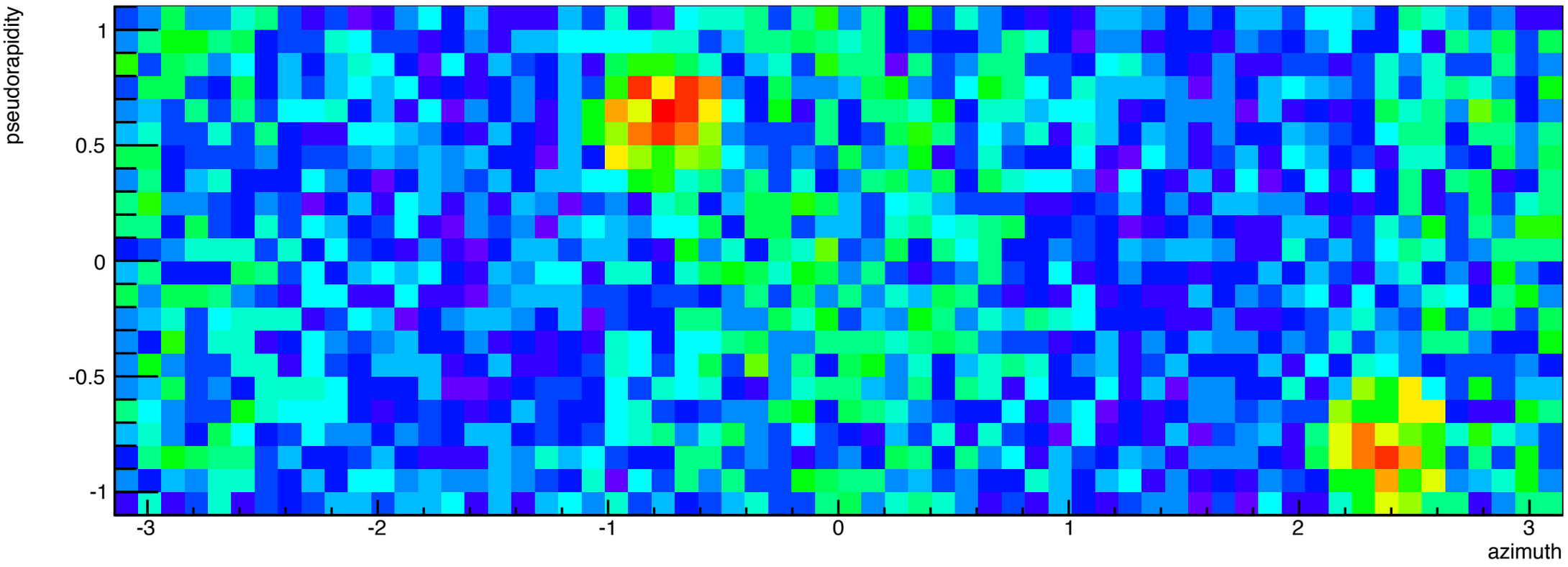
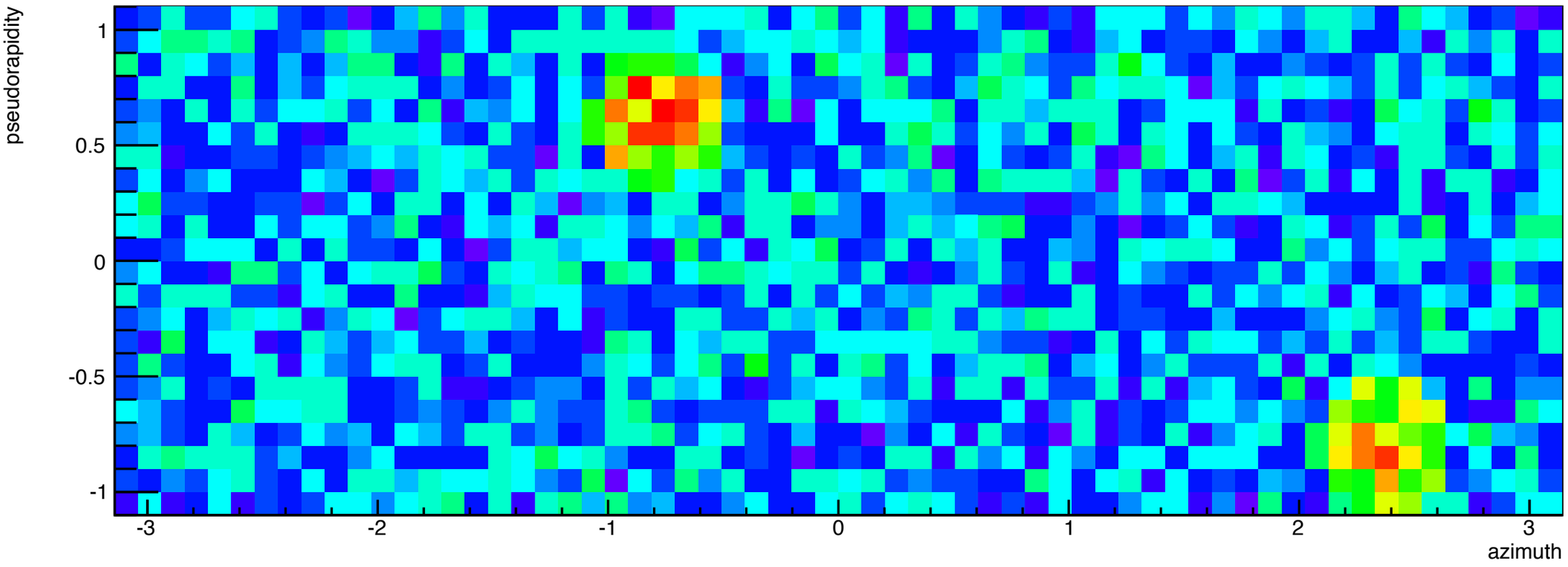
-1
-3
-2
-1
0
1
2
3
azimuth


pseudorapidity
1
0.5
0
-0.5
-1
-3
-2
-1
0
1
2
3
azimuth


pseudorapidity
1
0.5
0
-0.5
-1
-3
-2
-1
0
1
2
3
azimuth


pseudorapidity
1
0.5
0
-0.5
-1
-3
-2
-1
0
1
2
3
azimuth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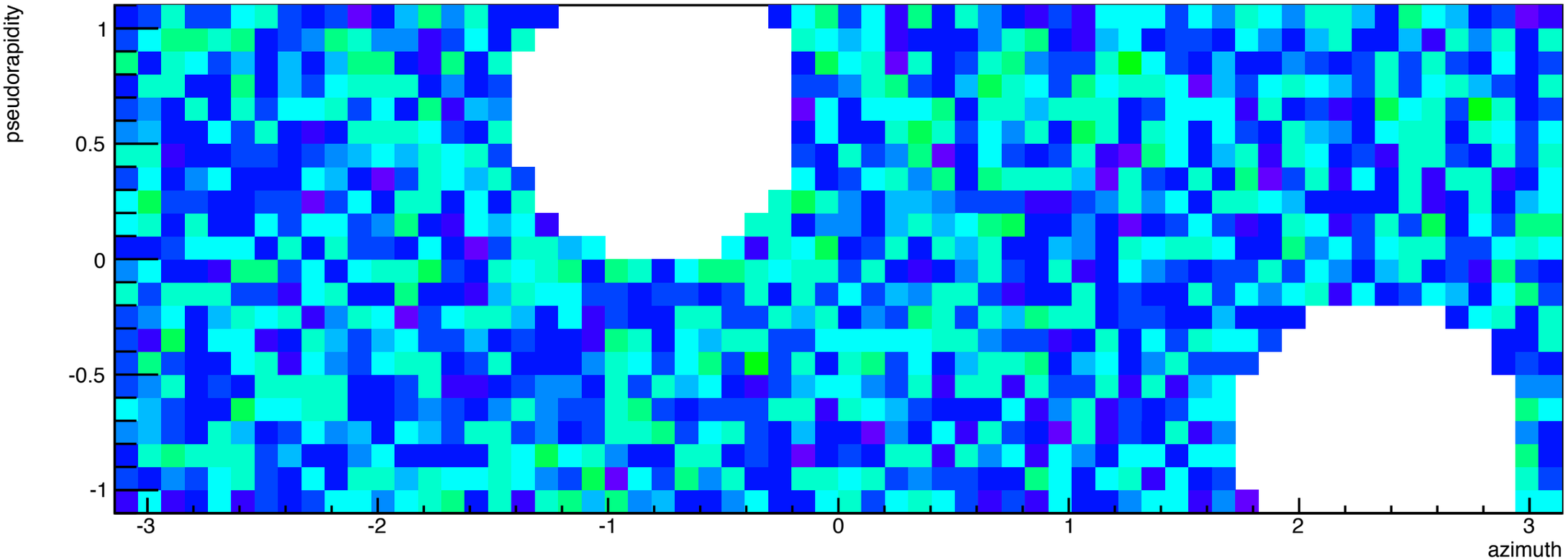
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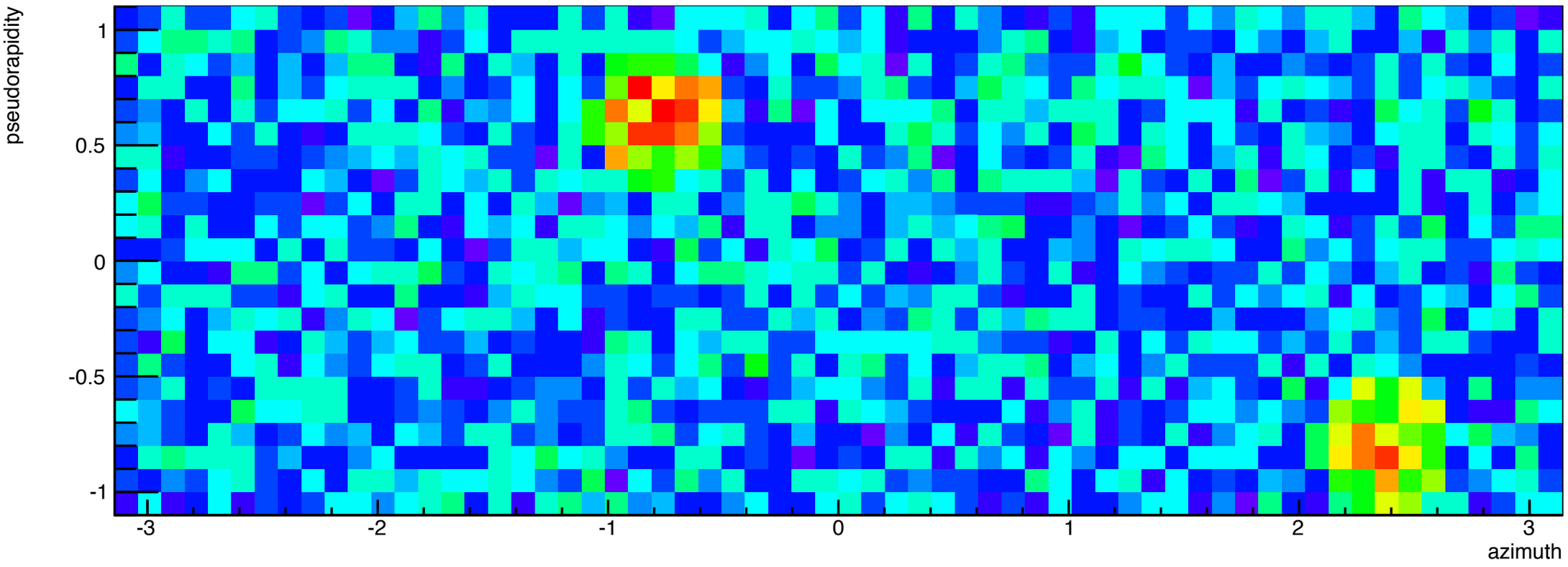
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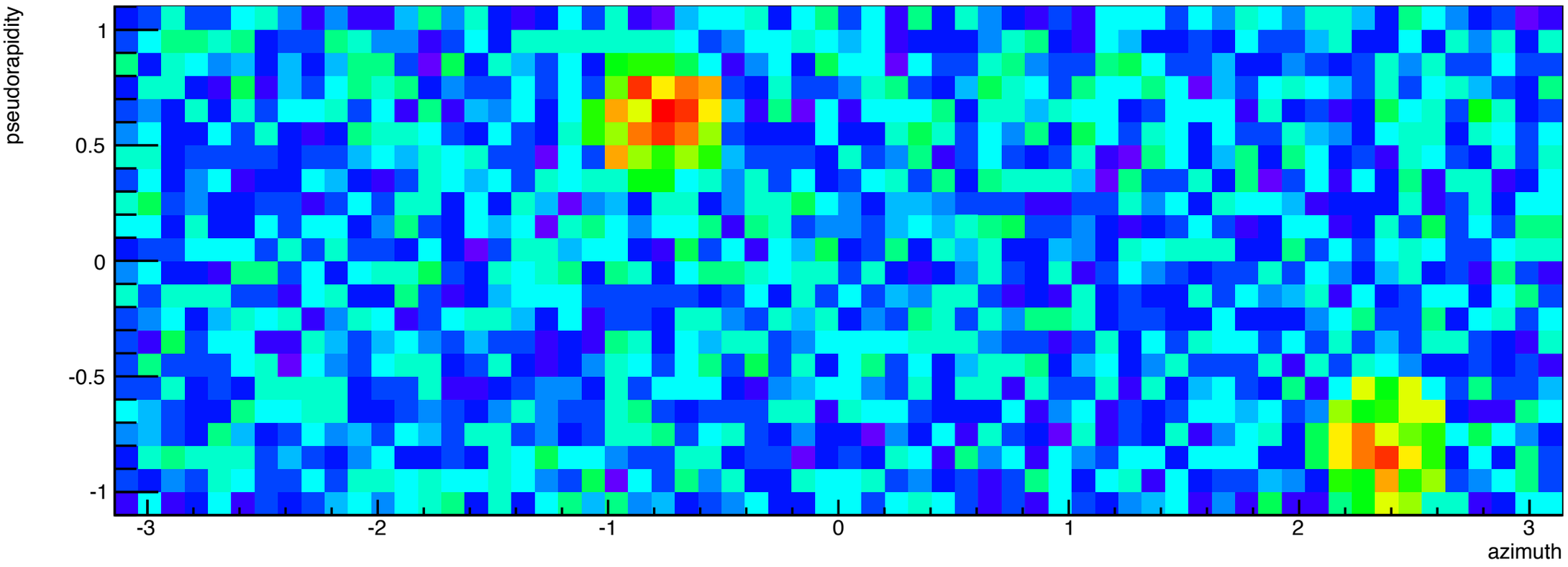
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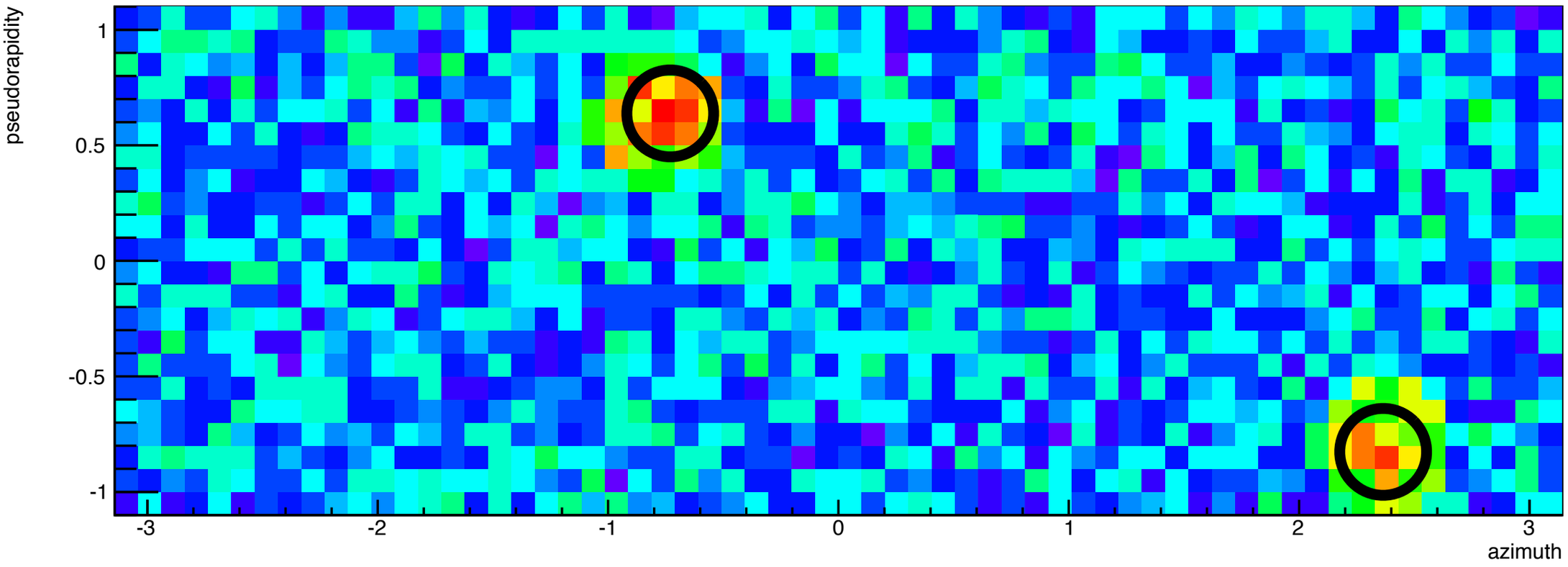
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